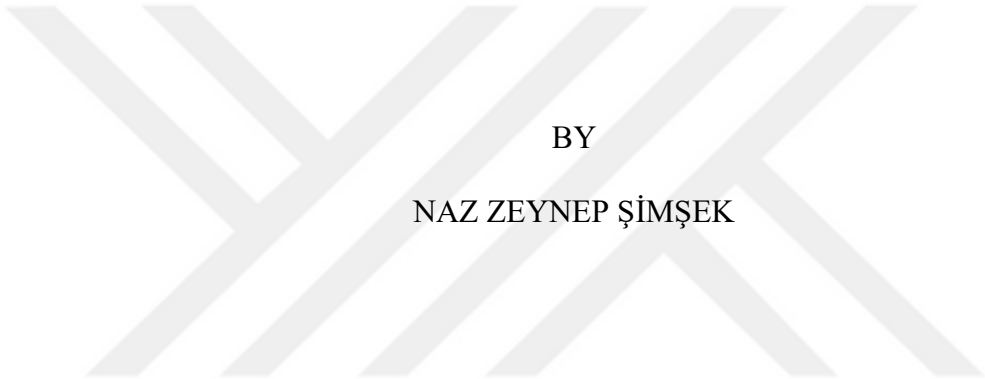


A LIFE CYCLE ASSESSMENT OF THE MEMBRANE PROCESSES APPLIED
FOR SALT RECOVERY IN REACTIVE DYEING

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
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NAZ ZEYNEP ŞİMŞEK

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Approval of the thesis:

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APPLIED FOR SALT RECOVERY IN REACTIVE DYEING**

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

A LIFE CYCLE ASSESSMENT OF THE MEMBRANE PROCESSES APPLIED FOR SALT RECOVERY IN REACTIVE DYEING

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Reactive dyeing in the textile industry requires the addition of a significant amount of salt and generates wastewater that is high in pollution load and particularly high in salt concentration. In the literature, a variety of Best Available Techniques (BATs) for the reduction of salt consumption in reactive dyeing and the reuse of treated wastewater are available. Among these techniques, Ultrafiltration (UF), Nanofiltration (NF), and combined UF+NF systems appear as the most efficient BATs, as they can provide both water and salt reclamation.

In the present study, the environmental impacts of the above-mentioned BAT applications and their potential to reduce salt usage in the reactive dyeing process were evaluated by following a Life Cycle Assessment (LCA) approach, and the results were compared with the direct wastewater discharge scenarios. Three distinct reactive dyeing methods were chosen for the scenarios: jet dyeing, jigger dyeing, and pad-steam dyeing. For the reuse scenarios, three different membrane treatment simulations (UF, NF, and UF+NF) were devised using WAVE software for the wastewater generated by each reactive dyeing method with the purpose of generating membrane filtration part of the inventory data that is to be integrated to the inventory data obtained from 21 textile mills in Turkey. The life cycle impacts of the alternative scenarios were compared with the direct discharge scenario using the SimaPro Ph.D.

v.9.2 LCA software. The results showed that the highest environmental impacts are on the Fine Particulate Matter Formation (FPMF) and Global Warming, Human Health (HGWP) impact categories for all the scenarios. The main contributors to both the impact categories were found to be energy consumption and dye usage in the dyeing process.

The results demonstrated that changing the reactive dyeing technique has an influence on the overall impact score, but the names of the categories with the highest environmental impacts did not change, even though their scores changed. For all the dyeing techniques, the highest impact is in the "Human Health" category.

Considering the overall impacts, a UF-only treatment that provides an efficient reclamation of salt was found to be the best application for each three reactive dyeing techniques. These results have the potential to serve as a guide for textile plants in reactive dyeing wastewater and salt recovery and reuse.

Keywords: Life Cycle Assessment, Reactive Dyeing Wastewater, Membrane Filtration, Salt Recovery, Best Available Techniques

ÖZ

REAKTİF BOYAMADA TUZ GERİ KAZANIMI İÇİN UYGULANAN MEMBRAN PROSESLERİNİN YAŞAM DÖNGÜSÜ DEĞERLENDİRMESİ

Şimşek, Naz Zeynep
Yüksek Lisans, Çevre Mühendisliği
Tez Yöneticisi: Prof. Dr. Ülkü Yetiş

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Tekstil endüstrisindeki reaktif boyama, önemli miktarda tuz ilavesi gerektirmekte ve ve kirlilik yükü ve özellikle tuz konsantrasyonu yüksek atık su üretmektedir. Literatürde, reaktif boyamada tuz tüketiminin azaltılması ve arıtılmış atık suyun yeniden kullanılması için çeşitli Mevcut En İyi Teknikler (METler) mevcuttur. Bu teknikler arasında Ultrafiltrasyon (UF), Nanofiltrasyon (NF) ve kombine UF+NF sistemleri, hem su hem de tuz geri kazanımı sağlayabilmeleri sebebiyle en verimli METler olarak görünmektedir.

Bu çalışmada, yukarıda bahsedilen MET uygulamalarının çevresel etkileri ve reaktif boyama prosesinde tuz kullanımını azaltma potansiyelleri Yaşam Döngüsü Değerlendirmesi (YDD) yaklaşımı izlenerek değerlendirilmiş ve sonuçlar doğrudan atık su deşarjı senaryoları ile karşılaştırılmıştır. Senaryolar için üç farklı reaktif boyama yöntemi seçilmiştir: jet boyama, jigger boyama ve pad-steam boyama. Yeniden kullanım senaryolarında, Türkiye'deki 21 tekstil fabrikasından elde edilen envanter verilerine entegre edilecek olan membran filtrasyon envanter verilerinin oluşturulması amacıyla her bir reaktif boyama yöntemi tarafından üretilen atık su için WAVE yazılımı kullanılarak üç farklı membran arıtma simülasyonu (UF, NF ve UF+NF) geliştirilmiştir. Membran arıtma sonuçları ve doğrudan deşarj senaryoları SimaPro Ph.D. v.9.2 YDD yazılımı yardımıyla karşılaştırılmıştır.

Sonuçlar, tüm senaryolar için en yüksek çevresel etkilerin İnce Partikül Madde Oluşumu (FPMF) ve Küresel Isınma, İnsan Sağlığı (HGWP) etki kategorilerinde olduğunu göstermiştir. Her iki etki kategorisine de başlıca katkıda bulunanların, boyama işlemindeki enerji tüketimi ve boya kullanımı olduğu bulunmuştur. YDD sonuçları ayrıca, reaktif boyama tekniğinin değiştirilmesinin toplam etki puanı üzerinde bir etkisi olduğunu ancak en yüksek çevresel etkiye sahip kategorilerin puanları değişse de isimlerinin değişmediğini göstermiştir. Tüm boyama teknikleri için en yüksek etki "İnsan Sağlığı" kategorisindedir.

Toplam çevresel etkiler göz önünde bulundurulduğunda, tuzun verimli bir şekilde geri kazanılmasını sağlayan yalnızca UF arıtımının her üç reaktif boyama tekniği için en iyi uygulama olduğu görülmüştür. Bu sonuçlar, tekstil fabrikaları için reaktif boyama atıksuları ve tuz geri kazanımı ve yeniden kullanımı konusunda bir rehber olma potansiyeline sahiptir.

Anahtar Kelimeler: Yaşam Döngüsü Değerlendirmesi, Reaktif Boyama Atık suyu, Membran Filtrasyonu, Tuz Geri Kazanımı, Mevcut En İyi Teknikler



To my family

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TABLE OF CONTENTS

ABSTRACT	v
ÖZ.....	vii
ACKNOWLEDGMENTS.....	x
TABLE OF CONTENTS	xii
LIST OF TABLES	xv
LIST OF FIGURES.....	xxi
LIST OF ABBREVIATIONS	xxiv
CHAPTERS	
1 INTRODUCTION.....	1
1.1 General	1
1.2 Objective and Scope of the Study	3
2 BACKGROUND.....	9
2.1 TEXTILE INDUSTRY	9
2.1.1 Textile Wet Processes.....	10
2.1.2 Textile Dyeing Processes.....	11
2.1.3 Dye Types Used in the Textile Industry	14
2.1.4 Reactive Dyes	15
2.2 REACTIVE DYEING WASTEWATER.....	20
2.2.1 Characterization of Reactive Dyeing Wastewater	21
2.2.2 Reactive Dyeing Wastewater Treatment and Reuse.....	25
2.2.3 Membrane Filtration	29
2.3 INTEGRATED POLLUTION PREVENTION AND CONTROL.....	32

2.4	LIFE CYCLE ASSESSMENT	35
2.4.1	Life Cycle Assessment Stages.....	37
3	LITERATURE REVIEW	45
3.1	Literature Review on the Membrane Treatment of Reactive Dyeing Wastewater.....	45
3.2	Literature Review on Reactive Dyeing LCA Studies	48
4	METHODOLOGY	53
4.1	Study Approach	53
4.2	Data Collection	54
4.2.1	BESTÜ Project Data	55
4.2.2	Environmental Impact Assessment Reports of Textile Plants	55
4.2.3	Literature Data.....	56
4.2.4	Reactive Dye Material Inventory	56
4.2.5	Atmospheric Emissions.....	58
4.3	Scenario Development	58
4.4	Membrane Process Design with WAVE Water Treatment Design	60
4.5	Life Cycle Assessment Study	65
4.5.1	Goal and Scope Definition	65
4.5.2	Life Cycle Inventory Analysis	69
4.5.3	Life Cycle Impact Assessment.....	70
4.5.4	Interpretation	77
5	RESULTS AND DISCUSSION	79
5.1	Membrane System Design and Inventory Data	80
5.1.1	Jet Dyeing.....	81

5.1.2	Jigger Dyeing	93
5.1.3	Pad Dyeing.....	104
5.2	Life Cycle Impact Assessment Results	115
5.2.1	Jet Dyeing LCA Results	115
5.2.2	Jigger Dyeing LCA Results	120
5.2.3	Pad Dyeing LCA Results	123
5.2.4	A Summary of LCA Results for Alternative Dyeing Techniques	127
6	CONCLUSIONS AND RECOMMENDATIONS	131
	REFERENCES	135
	APPENDICES.....	151
A.	Data Collected for Inventory Analysis	151
B.	Assumptions Made in LCA Study.....	159
C.	Details of Membrane Treatment Scenarios	161
D.	Details of ReCiPe 2016 Impact Assessment Method.....	195
E.	Normalized Results of Life Cycle Impact Assessment	200
F.	Process Contributions to Mid-Point Impact Categories	206
G.	Process Contributions to End-Point Impact Categories	289
H.	Tree Diagrams of Scenarios	303

LIST OF TABLES

TABLES

Table 2.1. Dye Types and Typical Applications.....	14
Table 2.2. Reactive Dye Types and Properties	16
Table 2.3. Characteristics of Reactive Dyeing Wastewater.....	23
Table 2.4. Characteristics of the Wastewater from Different Stages of Reactive Dyeing.....	25
Table 4.1 List of Textile Plants with EIA Reports.....	55
Table 4.2. Inventory for Reactive Orange 12 (per production of 1 kg RO-12)	57
Table 4.3. Specific Air Emission per kg Steam Used in Dyeing	58
Table 4.4. Studied Scenarios.....	59
Table 4.5. Typical Properties and Suggested Operation Conditions of IP-51XP Module	61
Table 4.6. Typical Properties and Suggested Operation Conditions of NF270-400/34i Module	62
Table 4.7. Typical Properties and Suggested Operation Conditions of IntegraFlux SFP-2860XP Module	63
Table 4.8. Membrane Removals of Specific Pollutants.....	64
Table 4.9. Impact Assessment Methods and Specifications	72
Table 4.10. Mid-point Impact Categories of ReCiPe 2016 and IMPACT World+ Methods.....	74
Table 4.11. Impact Assessment Methods Used in the Literature	75
Table 5.1. Reactive Dyeing Inventory of Jet Dyeing Scenarios (per 1 ton of fabric dyed)	87
Table 5.2. Membrane Treatment Inventory of Jet Dyeing Scenarios (per 1 ton of fabric dyed)	90
Table 5.3. Reactive Dyeing Inventory of Jigger Dyeing Scenarios (per 1 ton of fabric dyed)	98

Table 5.4. Membrane Treatment Inventory of Jigger Dyeing Scenarios (per 1 ton of fabric dyed).....	101
Table 5.5. Reactive Dyeing Inventory of Pad Dyeing Scenarios (per 1 ton of fabric dyed)	109
Table 5.6. Membrane Treatment Inventory of Pad Dyeing Scenarios (per 1 ton of fabric dyed).....	112
Table A. 1. Literature Inventory Data	151
Table A. 2. BESTÜ Project Inventory Data (Plant 1-7).....	153
Table A. 3. BESTÜ Project Inventory Data (Plant 8-15).....	154
Table A. 4. Turkish Textile Plants' Inventory Data (EIA Reports)	155
Table A. 5. Steam Production Details Defined in Ecoinvent Database	156
Table A. 6. Mass Balance for K. Acid Production.....	157
Table A. 7. Mass Balance for Meta Ureido Aniline (MUA) Production	157
Table A. 8. Commonly Found Chlorobenzene Species in the Textile Dyeing Wastewater	158
Table C. 1. Scenario 1.1 - UF System Overview	161
Table C. 2. Scenario 1.1 - Feed Water and Product Water Details	162
Table C. 3. Scenario 1.2. - NF System Flow Diagram Description	162
Table C. 4. Scenario 1.2 - NF System Overview	163
Table C. 5. Scenario 1.2 - Feed Water and NF Solute Concentrations	163
Table C. 6. Scenario 1.3 - UF Pretreatment System Overview	164
Table C. 7. Scenario 1.3 - Feed Water and Product Water Details	165
Table C. 8. Scenario 1.3 - NF System Flow Diagram Description	165
Table C. 9. Scenario 1.3 - NF System Overview	166
Table C. 10. Scenario 1.3 - Feed Water and NF Solute Concentrations	166
Table C. 11. Scenario 1.3 - UF+NF Overall System Summary	167
Table C. 12. Scenario 2.1 - UF System Overview	168
Table C. 13. Scenario 2.1 - Feed Water and Product Water Details	168
Table C. 14. Scenario 2.2 - NF System Flow Diagram Description	169
Table C. 15. Scenario 2.2 - NF System Overview	169

Table C. 16. Scenario 2.2 - Feed Water and NF Solute Concentrations.....	170
Table C. 17. Scenario 2.3 - UF Pretreatment System Overview	170
Table C. 18. Scenario 2.3 - Feed Water and Product Water Details.....	171
Table C. 19. Scenario 2.3 - NF System Flow Diagram Description.....	172
Table C. 20. Scenario 2.3 - NF System Overview	172
Table C. 21. Scenario 2.3 - Feed Water and NF Solute Concentrations.....	173
Table C. 22. Scenario 2.3 - UF+NF Overall System Summary.....	173
Table C. 23. Scenario 3.1 - UF System Overview	174
Table C. 24. Scenario 3.1 - Feed Water and Product Water Details.....	175
Table C. 25. Scenario 3.2 - NF System Flow Diagram Description.....	175
Table C. 26. Scenario 3.2 - NF System Overview	176
Table C. 27. Scenario 3.2 - Feed Water and NF Solute Concentrations.....	177
Table C. 28. Scenario 3.3 - UF Pretreatment System Overview	177
Table C. 29. Scenario 3.3 - Feed Water and Product Water Details.....	178
Table C. 30. Scenario 3.3 - NF System Flow Diagram Description.....	179
Table C. 31. Scenario 3.3 - NF System Overview	179
Table C. 32. Scenario 3.3 - Feed Water and NF Solute Concentrations.....	180
Table C. 33. Scenario 3.3 - UF+NF Overall System Summary.....	180
Table C. 34. Water and Salt Recovery Performances of Membrane Treatment Scenarios	181
Table D. 1. ReCiPe 2016 Perspectives and Definitions.....	195
Table D. 2. Details of Impact Categories and Calculation Steps in ReCiPe 2016	196
Table E. 1. Mid-point Impact Assessment Results of Jet Dyeing Scenarios	200
Table E. 2. End-point Impact Assessment Results of Jet Dyeing Scenarios	201
Table E. 3. Mid-point Impact Assessment Results of Jigger Dyeing Scenarios...	202
Table E. 4. End-point Impact Assessment Results of Jigger Dyeing Scenarios...	203
Table E. 5. Mid-point Impact Assessment Results of Pad Dyeing Scenarios	204
Table E. 6. End-point Impact Assessment Results of Pad Dyeing Scenarios.....	205
Table F. 1. Scenario 1.a (Jet-Baseline) Process Contributions to Mid-point Impact Categories (HGWP – MEP).....	206

Table F. 2. Scenario 1.a (Jet-Baseline) Process Contributions to Mid-point Impact Categories (TETP – AWCP)	209
Table F. 3. Scenario 1.1 (Jet-UF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)	213
Table F. 4. Scenario 1.1 (Jet-UF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)	216
Table F. 5. Scenario 1.2 (Jet-NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)	219
Table F. 6. Scenario 1.2 (Jet-NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)	223
Table F. 7. Scenario 1.3 (Jet-UF+NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)	226
Table F. 8. Scenario 1.3 (Jet-UF+NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)	229
Table F. 9. Scenario 2.a (Jigger-Baseline) Process Contributions to Mid-point Impact Categories (HGWP – MEP)	233
Table F. 10. Scenario 2.a (Jigger-Baseline) Process Contributions to Mid-point Impact Categories (TETP – AWCP)	236
Table F. 11. Scenario 2.1 (Jigger-UF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)	239
Table F. 12. Scenario 2.1 (Jigger-UF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)	242
Table F. 13. Scenario 2.2 (Jigger-NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)	246
Table F. 14. Scenario 2.2 (Jigger-NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)	249
Table F. 15. Scenario 2.3 (Jigger-UF+NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)	252
Table F. 16. Scenario 2.3 (Jigger-UF+NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)	256

Table F. 17. Scenario 3.a (Pad-Baseline) Process Contributions to Mid-point Impact Categories (HGWP – MEP).....	259
Table F. 18. Scenario 3.a (Pad-Baseline) Process Contributions to Mid-point Impact Categories (TETP – AWCP).....	263
Table F. 19. Scenario 3.1 (Pad-UF) Process Contributions to Mid-point Impact Categories (HGWP – MEP).....	266
Table F. 20. Scenario 3.1 (Pad-UF) Process Contributions to Mid-point Impact Categories (TETP – AWCP).....	270
Table F. 21. Scenario 3.2 (Pad-NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP).....	273
Table F. 22. Scenario 3.2 (Pad-NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP).....	277
Table F. 23. Scenario 3.3 (Pad-UF+NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP).....	281
Table F. 24. Scenario 3.3 (Pad-UF+NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP).....	284
Table G. 1. Jet Dyeing Scenarios Process Contributions to Human Health End-point Impact Category.....	289
Table G. 2. Jet Dyeing Scenarios Process Contributions to Ecosystems End-point Impact Category.....	290
Table G. 3. Jet Dyeing Scenarios Process Contributions to Resources End-point Impact Category.....	292
Table G. 4. Jigger Dyeing Scenarios Process Contributions to Human Health End-point Impact Category.....	293
Table G. 5. Jigger Dyeing Scenarios Process Contributions to Ecosystems End-point Impact Category.....	295
Table G. 6. Jigger Dyeing Scenarios Process Contributions to Resources End-point Impact Category.....	296
Table G. 7. Pad Dyeing Scenarios Process Contributions to Human Health End-point Impact Category.....	298

Table G. 8. Pad Dyeing Scenarios Process Contributions to Ecosystems End-point
Impact Category 299

Table G. 9. Pad Dyeing Scenarios Process Contributions to Resources End-point
Impact Category 301



LIST OF FIGURES

FIGURES

Figure 1.1. Schematic Representation of the Study Scope	4
Figure 1.2. Study Methodology Flow Diagram	6
Figure 2.1. Textile Chain	10
Figure 2.2. Textile Production Flow Diagram	11
Figure 2.3. Reactive Dye General Structure	15
Figure 2.4. Jigger Dyeing Machine.....	18
Figure 2.5. Padding Machine	19
Figure 2.6. Jet Dyeing Machine	20
Figure 2.7. Representation of a Membrane Treatment System	30
Figure 2.8. Membrane Classification based on Separated Components.....	30
Figure 2.9. LCA Framework.....	37
Figure 2.10. Life-cycle Stages	38
Figure 2.11. Representative System Boundaries, Inputs and Outputs	40
Figure 2.12. LCIA Key Elements	41
Figure 2.13. Mid-point and End-point Impact Categories of ReCiPe2016 Impact Assessment Method	43
Figure 4.1. System Boundary for Membrane Treatment Scenarios.....	66
Figure 4.2. System Boundary for Direct Discharge Baseline Scenario	67
Figure 4.3. Databases Present in SimaPro Library	68
Figure 5.1. Scenario 1.1 – Direct UF System for Jet Dyeing Wastewater	82
Figure 5.2. Scenario 1.2 – Direct NF System for Jet Dyeing Wastewater	84
Figure 5.3. Scenario 1.3 - UF+NF Treatment System for Jet Dyeing	85
Figure 5.4. Scenario 1.3 – UF Pretreatment System for Jet Dyeing Wastewater ...	85
Figure 5.5. Scenario 1.3 – NF System for Jet Dyeing Wastewater.....	86
Figure 5.6. Scenario 2.1 – Direct UF System for Jigger Dyeing Wastewater	94
Figure 5.7. Scenario 2.2 – Direct NF System for Jigger Dyeing Wastewater	95
Figure 5.8. Scenario 2.3 - UF+NF Treatment System for Jigger Dyeing.....	96

Figure 5.9. Scenario 2.3 – UF Pretreatment System for Jigger Dyeing Wastewater	96
Figure 5.10. Scenario 2.3 – NF System for Jigger Dyeing Wastewater.....	97
Figure 5.11. Scenario 3.1 – Direct UF System for Pad Dyeing Wastewater	105
Figure 5.12. Scenario 3.2 – Direct NF System for Pad Dyeing Wastewater	106
Figure 5.13. Scenario 3.3 - UF+NF Treatment System for Pad Dyeing	107
Figure 5.14. Scenario 3.3 – UF Pretreatment System for Jigger Dyeing Wastewater	107
Figure 5.15. Scenario 3.3 – NF System for Pad Dyeing Wastewater	108
Figure 5.16. Comparative End-Point Environmental Impacts for Jet Dyeing	116
Figure 5.17. Comparative Mid-Point Environmental Impacts for Jet Dyeing	117
Figure 5.18. Main Contributors to FPMF Impact Category for Jet Dyeing	118
Figure 5.19. Main Contributors to HGWP Impact Category for Jet Dyeing	119
Figure 5.20. Comparative End-Point Environmental Impacts for Jigger Dyeing .	120
Figure 5.21. Comparative Mid-Point Environmental Impacts for Jigger Dyeing .	121
Figure 5.22. Main Contributors to FPMF Impact Category for Jigger Dyeing.....	122
Figure 5.23. Main Contributors to HGWP Impact Category for Jigger Dyeing ...	123
Figure 5.24. Comparative End-Point Environmental Impacts for Pad Dyeing.....	124
Figure 5.25. Comparative Mid-Point Environmental Impacts for Pad Dyeing.....	125
Figure 5.26. Main Contributors to FPMF Impact Category for Pad Dyeing	126
Figure 5.27. Main Contributors to HGWP Impact Category for Pad Dyeing	126
Figure 5.28. Comparative End-Point Impacts for Alternative Dyeing Techniques	128
Figure C. 1. Scenario 1.1 Mass Balance Flow Chart.....	182
Figure C. 2. Scenario 1.2 Mass Balance Flow Chart.....	183
Figure C. 3. Scenario 1.3 Mass Balance Flow Chart.....	185
Figure C. 4. Scenario 2.1 Mass Balance Flow Chart.....	187
Figure C. 5. Scenario 2.2 Mass Balance Flow Chart.....	188
Figure C. 6. Scenario 2.3 Mass Balance Flow Chart.....	189
Figure C. 7. Scenario 3.1 Mass Balance Flow Chart.....	191

Figure C. 8. Scenario 3.2 Mass Balance Flow Chart	192
Figure C. 9. Scenario 3.3 Mass Balance Flow Chart	193
Figure H. 1. Tree Diagram of Scenario 1.a.....	303
Figure H. 2. Tree Diagram of Scenario 1.1.....	305
Figure H. 3. Tree Diagram of Scenario 1.2.....	307
Figure H. 4. Tree Diagram of Scenario 1.3.....	309
Figure H. 5. Tree Diagram of Scenario 2.a.....	311
Figure H. 6. Tree Diagram of Scenario 2.1.....	313
Figure H. 7. Tree Diagram of Scenario 2.2.....	315
Figure H. 8. Tree Diagram of Scenario 2.3.....	317
Figure H. 9. Tree Diagram of Scenario 3.a.....	319
Figure H. 10. Tree Diagram of Scenario 3.1.....	321
Figure H. 11. Tree Diagram of Scenario 3.2.....	323
Figure H. 12. Tree Diagram of Scenario 3.3.....	325

LIST OF ABBREVIATIONS

AWCP	Water consumption, Aquatic ecosystem
BATs	Best Available Techniques
BREF	Best Available Techniques Reference Document
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
EU	European Union
FEP	Freshwater eutrophication
FETP	Freshwater ecotoxicity
FFP	Fossil resource scarcity
FGWP	Global warming, Freshwater ecosystems
FPMF	Fine particulate matter formation
GLO	Global
HGWP	Global warming, Human health
HOFP	Ozone formation, Human health
HTPc	Human carcinogenic toxicity
HTPnc	Human non-carcinogenic toxicity
HWCP	Water consumption, Human health
IED	Industrial Emissions Directive
IPPC	Integrated Pollution Prevention and Control
IRP	Ionizing radiation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Inventory Assessment
LOP	Land use
MEP	Marine eutrophication
METP	Marine ecotoxicity
MF	Microfiltration
NF	Nanofiltration

ODP	Stratospheric ozone depletion
RER	Rest of the Europe
RO	Reverse Osmosis
RoW	Rest of the World
SAC	Spectral Absorption Coefficient
SOP	Mineral resource scarcity
TAP	Terrestrial acidification
TDS	Total Dissolved Solids
TETP	Terrestrial ecotoxicity
TGWP	Global warming, Terrestrial ecosystems
TOC	Total Organic Carbon
TOFP	Ozone formation, Terrestrial ecosystems
TS	Total Solids
TSS	Total Suspended Solids
TWCP	Water consumption, Terrestrial ecosystem
UF	Ultrafiltration

CHAPTER 1

INTRODUCTION

1.1 General

The accelerated growth of the textile industry, in response to the world's increasing population, is leading to massive industrial pollution in the environment in addition to significant raw material, water, and energy consumption (Toprak & Anis, 2017). It is anticipated that the raw material and resource consumption by the textile industry will considerably increase over the course of the following years. The textile industry is responsible for a significant portion of worldwide water pollution. Approximately 20% of the wastewater generated from industrial activities originates from the textile industry. In particular, dyeing and finishing processes have a great contribution to the generated wastewater amount and the high pollution load (Muthu, 2019). Non-degradable organic compounds, hazardous chemicals, heavy metals, and organic halogens are generally found in dyeing and finishing wastewater (Keskin et al., 2021).

Cotton accounts for the vast majority of the total volume of cellulosic materials, and accordingly, the dyeing processes of cotton fabrics have an important place in textile production. Reactive dyes have become the so-called standard for cotton dyeing for their brightness of colors and outstanding ability to resist fading on the fabric, which is terminologically defined as the "color fastness property" (Christie, 2007). In dyeing with reactive dyes, a significant amount of salt, along with other auxiliary chemicals, is required in the dye bath to achieve the desired color in the textile. Due to its low fixation ratio, a significant amount of unfixed reactive dye remains in the dyebath. These constituents cause the wastewater to contain a high concentration of color, chemical oxygen demand (COD), total dissolved solids (TDS), and salt. Considering the volume and rate of production in the textile industry, it is clear that

sustainable management of reactive dyeing wastewater is of great importance. At this point, cleaner production practices and integrated pollution prevention policies play an important role.

The Industrial Emission Directive (IED) (2010/75/EU) that replaced the Integrated Pollution Prevention and Control Directive (IPPC Directive) (96/61/EC) is the leading regulatory instrument of the EU in controlling industrial pollution. The Directive requires industrial installations to have permits based on the Best Available Techniques (BATs), which are defined in the sectoral BAT Reference Documents (BREFs). ‘Best Available Techniques’ means “the economically and technically viable techniques which are the best for preventing or minimising emissions and impacts on the environment as a whole”. The BREFs or the conclusions of these documents not only lay down BATs but also the Emission Levels Associated with BATs (BAT-AELs) and environmental performance levels associated with BATs.

The textile industry is also one of the sectors falling under the IED due to its great contribution to environmental pollution. Recovery and reuse of reactive dyeing wastewater and its salt content are among the main issues addressed by the Textile Industry BREF (TXT BREF) Document. For reuse and/or recycling of dyeing process baths, the use of membrane filtration applications such as Microfiltration (MF), Ultrafiltration (UF), Nanofiltration (NF), and Reverse Osmosis (RO) is suggested as a BAT in the TXT BREF (European Commission, 2022). In a previous study, Erkanlı et al. (2017) investigated the possible use of the UF membrane process for the recovery of salt and water from reactive dyeing wastewater, and Lin et al. (2015) studied the use of NF membranes for the same purpose. The results of these studies indicate that UF and NF treatments may be effective options for the reuse of both salt and water from the reactive dyeing process. Further, in the study of Jiang et al. (2018), it is stated that the treatment of reactive dyeing wastewater with UF membranes allows complete salt and water recovery with a high color rejection.

Although all these reuse and/or recycling processes have been presented as effective methods for reducing and preventing pollution and also for salt recovery, there is no

clear guidance in the TXT BREF regarding which technique should be selected. More specifically, there is no evaluation of the environmental impacts of alternative membrane separation processes. Additionally, salt recovery methods using membrane filtration methods (single or sequential applications of UF, NF and RO) in the textile dyeing process have never been evaluated with a Life Cycle Assessment (LCA) approach before, which is an important gap in the literature. Therefore, the need for the environmental impact assessment of the proposed salt recovery BATs with the use of membrane filtration techniques forms the basis of this study.

1.2 Objective and Scope of the Study

This study aims to evaluate and compare the environmental impacts of the reuse scenarios devised to reduce the amount of water used and salt applied in reactive dyeing by means of membrane filtration and that of the direct wastewater discharge scenario with the LCA approach. The fact that the membranes allow the passage of salt while removing dyes and pollutants allows the reuse of reactive dyeing wastewater in the dyeing process after the membrane treatment. Thus, suggested membrane applications and the reuse of brackish permeate in the reactive dyeing process are the focus of the present LCA study. The schematic representation of the scope of this study is given in Figure 1.1.

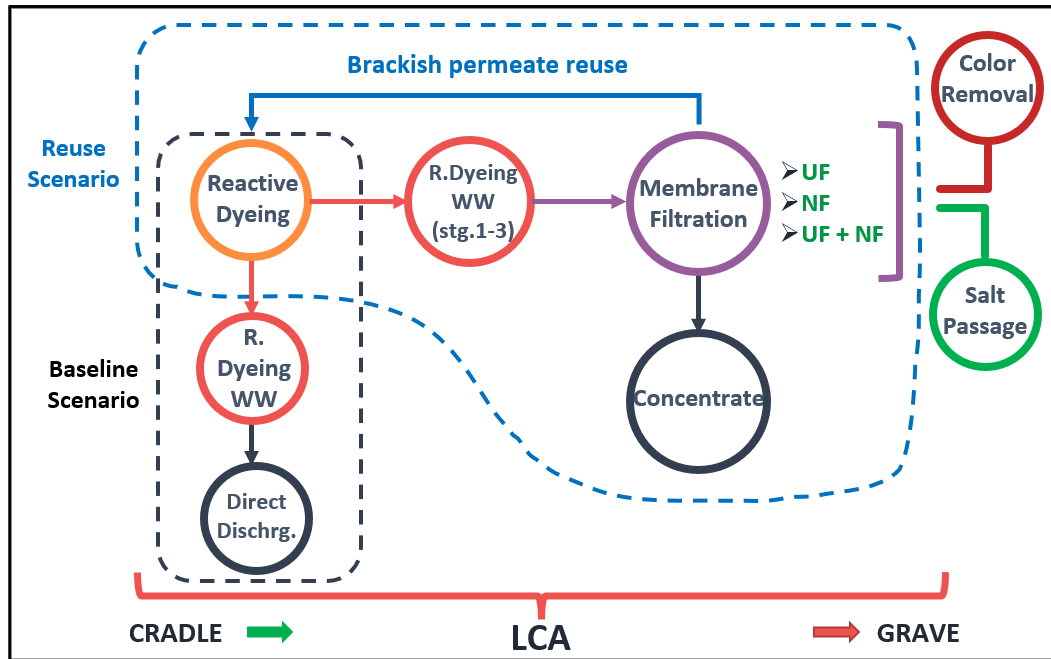


Figure 1.1. Schematic Representation of the Study Scope

The system boundary of the LCA study was determined as “cradle-to-grave”, which includes raw material acquisition, reactive dyeing processes, and wastewater treatment stages. In order to design the membrane treatment scenarios with meaningful wastewater flow rate values, the functional unit was determined as "1 ton of fabric dyed ".

The data required for the inventory analysis of the reactive dyeing process were obtained from the textile plants investigated under the BESTÜ Project (The Ministry of Environment Urbanization and Climate Change, 2020), Environmental Impact Assessment (EIA) Reports of several textile plants in Turkey, and the studies in the literature. This set of inventory data was collected for three different reactive dyeing methods: jet, jigger, and pad-steam dyeing. When necessary, average or median values of large data sets were generated. This inventory study enabled the determination of the inputs and outputs of the reactive dyeing process as well as the amount and characteristics of the process wastewater.

For the compilation of the inventory data for the membrane treatment scenarios, three different treatment simulations were constructed for each dyeing method using

the WAVE software, developed by DuPont Water Solutions, because there is no operational data available in the literature for the considered membrane treatment systems. Moreover, reactive dyeing wastewater reclamation via the application of direct UF treatment has not been applied on a full scale yet. For the WAVE simulations, only the feed water characteristic data, which is one of the outputs of the reactive dyeing inventory studies, is entered into the software as external data. The life cycle impact assessment was conducted with SimaPro Ph.D. v.9.2 software following the completion of the life cycle inventory assessment. For the impact assessment, the ReCiPe 2016 Endpoint (H) method was used. The methodology flow chart of the study is presented in Figure 1.2.

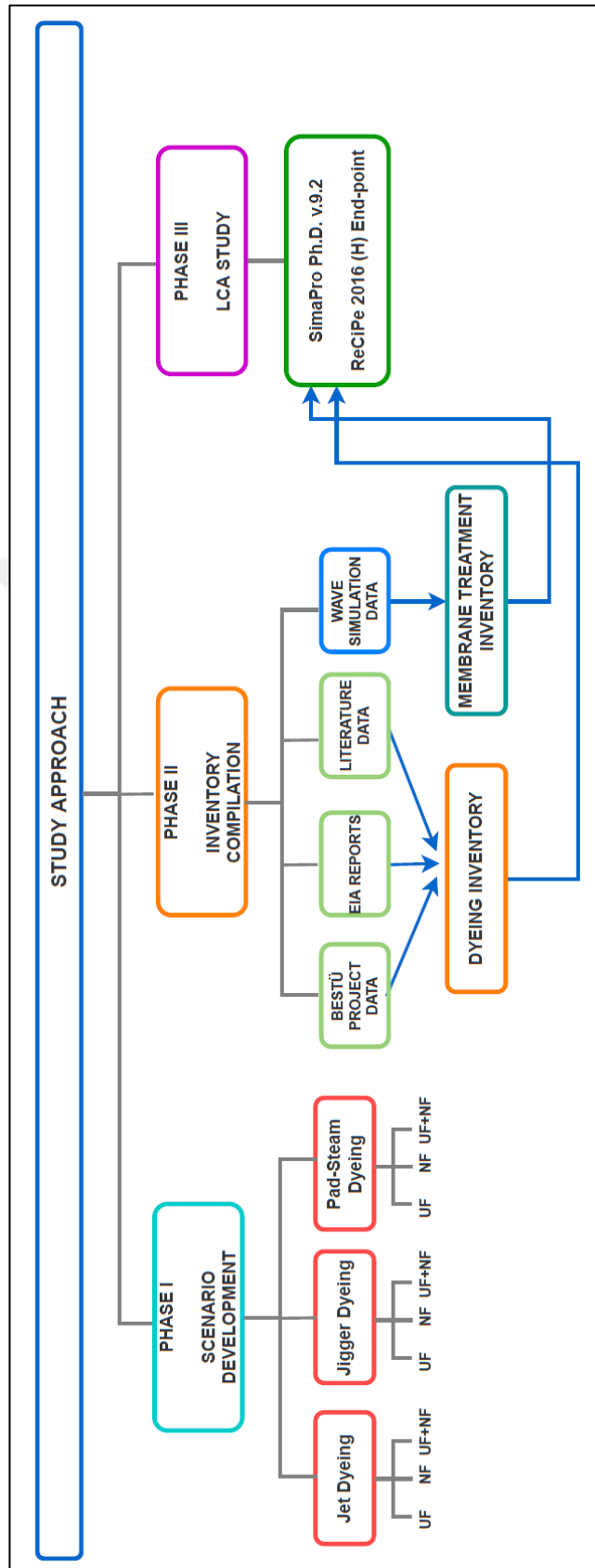


Figure 1.2. Study Methodology Flow Diagram

The results of this study are expected to make an important scientific contribution by determining the environmental impacts of membrane-based textile dyeing wastewater treatment and salt and water recovery applications. In addition, the fact that the treatment performances of three different membrane treatment applications were evaluated with the WAVE software, and the environmental impacts were evaluated with the LCA study, giving the opportunity to compare these membrane applications with each other. From an industrial point of view, the comparison of the environmental impacts of membrane treatment and brackish water recovery with the direct discharge scenarios is also expected to make a significant contribution by supporting the decision-making process of textile plants in process selection. Therefore, the results of this study are regarded to serve as a guide to textile plants in reactive dyeing wastewater and salt recovery and reuse.

Due to the lack of studies evaluating the environmental impacts of salt and water recovery through membrane treatment of reactive dyeing wastewater with an LCA approach, this study represents an original and novel contribution to this field of literature. The novelty of this study was further enhanced by the use of WAVE software for membrane treatment inventory data.

This thesis consists of six chapters. In Chapter 1, the introduction and objective and scope of the study are explained. In Chapter 2, background information about the textile industry, reactive dyeing, and the LCA approach is presented. In Chapter 3, literature reviews on the membrane treatment of reactive dyeing wastewater and reactive dyeing LCA studies are given. In Chapter 4, the membrane treatment design and LCA methodology followed in this study are explained in detail. In Chapter 5, the results of membrane treatment simulation and LCA studies are presented, interpreted, and discussed. In the last chapter, Chapter 6, a summary of the results and the conclusions are presented.

CHAPTER 2

BACKGROUND

2.1 TEXTILE INDUSTRY

The textile industry consists of many sub-sectors that produce textile-related commodities through diverse and lengthy processes. These commodities can be fabric, yarn, and fibers, and they are further processed into clothing, home textile products, and other industrial goods. The type of manufacturing process depends on the final product aimed to be produced.

In the textile industry, two fiber types, natural and man-made, are used. The natural fibers originate from animals or vegetables (Baydar et al., 2015), and they can be in cellulosic, mineral, or protein structures (Cook, 1984a). Man-made fibers can be classified into two categories such as natural polymer fibers and synthetic fibers (Cook, 1984b).

In general terms, the production chain starts with processing raw material into fabric or related products and finishes with the dyeing and finishing steps (Babu et al., 2007). The general diagram for processes in the textile industry is given in Figure 2.1.

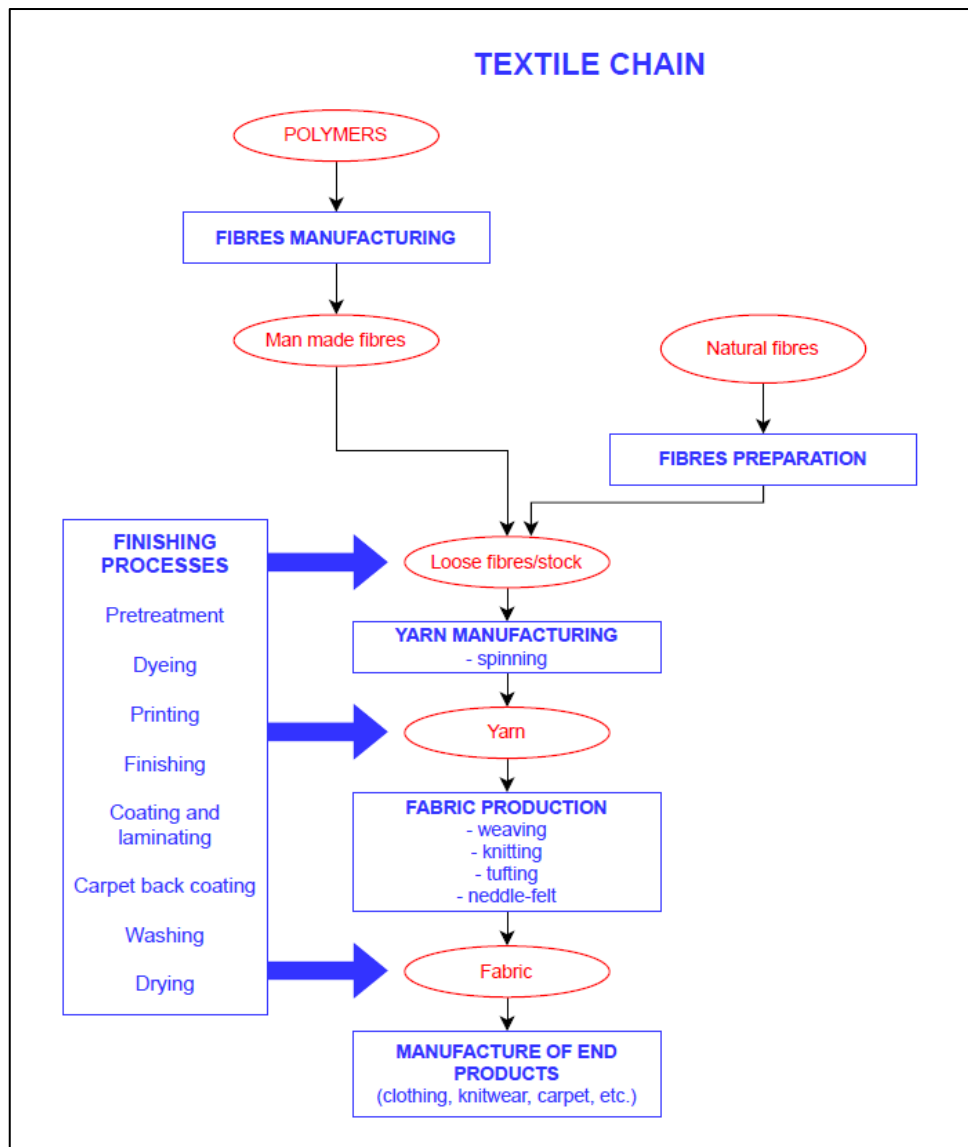


Figure 2.1. Textile Chain (European Commission, 2022)

2.1.1 Textile Wet Processes

Textile production processes can be analyzed under two main classes such as dry processes and wet processes. Among these two manufacturing groups, wet processing has specific importance as the largest amount of water consumption occurs in this process. In addition to the significant water consumption, the characteristics of the effluent wastewater from these processes are a great concern

due to the constituents such as chemicals, unfixed dyes, salt, and other auxiliaries (Madhav et al., 2018). A detailed diagram for textile production, including wet processing, is given in Figure 2.2.

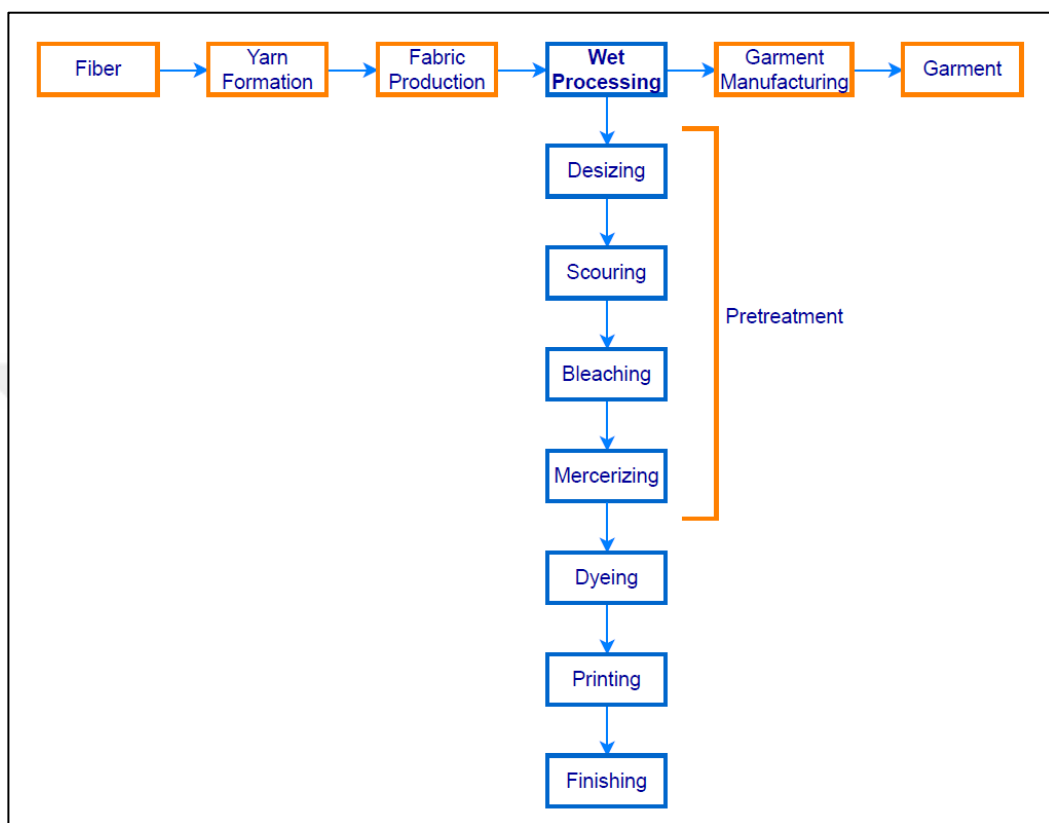


Figure 2.2. Textile Production Flow Diagram (Madhav et al., 2018)

Among the wet processes, the dyeing step is of particular importance, as this step is accounted for more than 80% of water consumption and wastewater production in the whole textile manufacturing (Zhang et al., 2018).

2.1.2 Textile Dyeing Processes

The dyeing process is simply defined as the uniform application of dye to the textile substrate (e.g. fabric) for the coloration of textile materials. Dyestuff molecules possess a chromophoric group, which is a group that is capable of reacting with light and giving the appearance of the color. In order to get the desired color on

textiles, it is necessary to use various chemicals and auxiliaries such as salt, sodium hydroxide, sodium carbonate, etc. The formulation of the dyestuff may already include certain auxiliaries; nevertheless, it is a far more typical practice to add additional auxiliary agents to the dyeing liquor at the upcoming stages. Since auxiliaries are often removed from the substrate after dyeing, auxiliary residues are eventually detected in the emissions (European Commission, 2022). The complete dyeing procedure comprises three main consecutive stages, dye adsorption, dye diffusion into the substrate, and dye fixation. Textile dyeing processes are not straightforward processes, and there are several different factors affecting the success of dyeing performed. These factors include solution properties, textile properties, final product, dye recipe, and machinery selection (Chakraborty, 2014). The dyeing process can be conducted using three methods: continuous, semi-continuous, or batch (exhaust) dyeing (Clark, 2011b). When choosing among the methods, it is important to consider the textile properties, the type of dye to be used, the availability of the equipment, and the total cost involved.

2.1.2.1 Batch (Exhaust) Dyeing

The batch dyeing process involves adding a solution containing the dye and the auxiliaries to a dyeing machine and slowly bringing the solution to a state of equilibrium over one to two hours (Chakraborty, 2014).

Initially, the dye is absorbed onto the fiber's outer surface, where it is subsequently diffused and transferred all through the fiber during dyeing. The usage of auxiliaries and temperature control speeds up and optimizes the dye uptake and level of fixation. The exhausted dye bath is emptied, and the dyed fiber is washed for the removal of unfixed dyes and auxiliaries when it is determined that the required final shade is achieved. In batch dyeing, the liquor ratio is a critical factor. This is the ratio of the total dry weight of fiber to total liquor. To be clear, a liquor ratio of 1:10 indicates that for every kilogram of textile material, 10 liters of water must be added to the mixture. Dyeing machines' liquor ratios can be very different

from one another, depending not only on the substrate to be dyed but also on the substrate's degree of hydrophilicity. For woven and knitted fabric and tufted carpet, the liquor ratio may change from 1:3 to 1:40 depending on both the equipment used and the type of textile material (European Commission, 2022).

2.1.2.2 Semi-continuous and Continuous Dyeing

In both continuous and semi-continuous dyeing, padding or other application methods are used to apply the dye liquor to the textile material. Textiles are dyed in a “dip trough” with dye liquor, which they are fed in continuous mode. In these semi-continuous or continuous machines, the dye liquor is absorbed by the fabric as it moves through the pad, then it is compressed between rubber rolls (European Commission, 2022). Retained amount of dye liquor by the textile material is defined as “pick-up” in the textile terminology. In the intermediate drying steps of continuous dyeing methods, a low level of pick-up is preferred as it refers to the minimized dye liquor migration in the substrate, meaning the energy saving in the drying step (Clark, 2011a). However, at very low pick-up levels uneven colorations might be observed in the finished fabric. To solve this undesirable situation, it is necessary to prepare dyeing liquors with higher concentrations. Although there are various studies enabling working at low pick-up levels, the optimum ratio is defined as 60-70%, in general.

In continuous dyeing, as the name implies, all dyeing, fixing, and washing steps are operated continuously. In semi-continuous dyeing, the dye is continuously applied by padding, whereas fixing and washing are operated in discontinuous mode. This is the sole difference between semi-continuous and continuous dyeing (European Commission, 2022).

2.1.3 Dye Types Used in the Textile Industry

There are various types of dyes categorized based on their source, chemical structure, ionic nature, solubility in the water, and application. Dyeing materials used in textile dyeing possess various different properties. In order to obtain the desired shades, the manner of attachment of dyes to fibers and fastness properties should be taken into consideration in the correct dye selection (Chakraborty, 2014). The types of dyes used in textile manufacturing are listed in Table 2.1.

Table 2.1. Dye Types and Typical Applications (Clark, 2011a; European Commission, 2022; Wang et al., 2011)

Dye Type	Typical Application	Dyeing Method
Direct dyes	Cotton, rayon, linen, jute, silk, polyamide fibers	Batch, pad-batch, pad-steam, pad-jig
Vat dyes	Cotton, polyamide, polyester	Batch, pad-steam
Sulfur dyes	Cotton, viscose, polyamide, polyester	Batch, pad-steam, pad-dry/pad-steam
Azoic dyes	Cotton, viscose, cellulose acetate, linen, polyester	Batch, padding
Reactive dyes	Cotton, viscose, wool, polyamide	Batch, pad-batch, pad-steam, pad-dry
Acid dyes	Polyamide (70 – 75 %), wool (25 – 30 %), silk, acrylic fibers	-
Disperse dyes	Polyester, acetate, polyamide, acrylic	-
Basic dyes	Acrylic fibers	-

Cotton is the most widely used fiber type in the textile industry, and reactive dyes are the most common class of dyes used to color cotton fabrics as their application on cotton gives the most successful results in cotton dyeing. Reactive dyes are anionic dyes that are soluble in water, and they are purposely engineered to allow

the removal of hydrolyzed dye simply by soap washing and rinsing (Mahapatra, 2016).

The application methods and the dye properties are of great importance as they are the key factors determining the characterization of the wastewater generated in the dyeing process. Therefore, in the following section, the features of reactive dyes are discussed in further detail.

2.1.4 Reactive Dyes

The reactive dyes, with a wide spectrum of colors and fastness, are widely used due to their easy application and reproducibility features (Mahapatra, 2016). These water-soluble, anionic dyes react with the cellulose textile material with covalent bonds through nucleophilic addition or substitution mechanisms (Chakraborty, 2014).

The reactive dyes contain four functional groups: the chromophoric group, solubilizing part, bridging, and reactive site. Chakraborty (2014) represented the reactive system as shown in Figure 2.3.

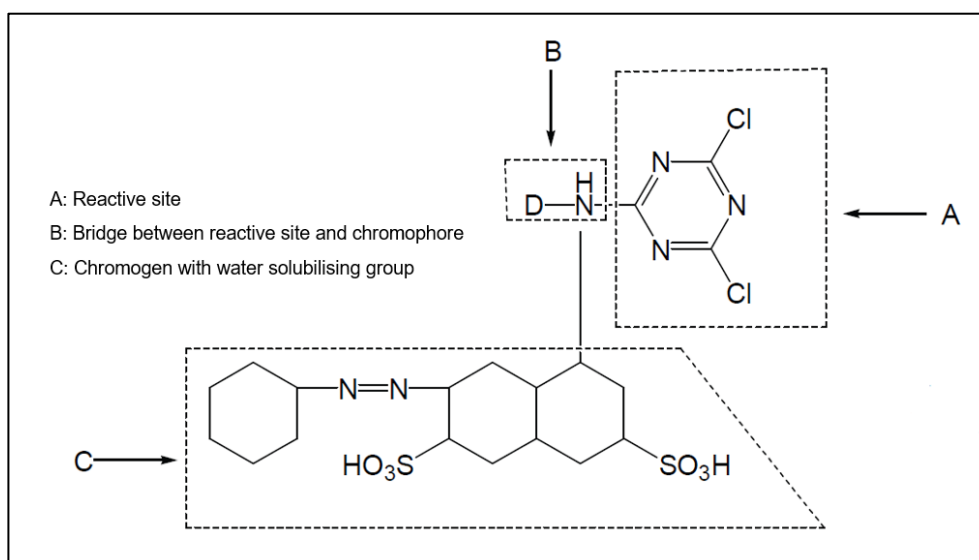


Figure 2.3. Reactive Dye General Structure (Chakraborty, 2014)

Among these four functional groups, chromogen gives the color of the dye. The solubility of the dye in water is determined by the presence of a solubilizing group connected to the chromophoric group. The bridging group forms a connection between the reactive system and the chromogen. The reactive site is responsible for the covalent bond formation (Clark, 2011a; Mahapatra, 2016).

On the basis of the reactive group type and the number of functional groups present in their chemical structures, reactive dyes can be categorized into five main types. These reactive dye types are given in Table 2.2, together with their main reactive groups and dyeing conditions.

Table 2.2. Reactive Dye Types and Properties (Mahapatra, 2016)

Type of Reactive Dye	Reactive Radical Group	Dyeing Conditions
Bi-functional dyes (ME dyes)	Monochlorotriazinyl and vinyl sulphone	- Suitable for cellulosic fibers - Exhaust dyeing at 60 °C - Continuous dyeing
Vinyl sulphone dyes	Vinyl sulphone	- Exhaust dyeing at 60 °C - Continuous dyeing
H-E dyes	Monochlorotriazinyl	- Suitable for polyester/cotton fiber blends (high fixation) - Suitable for dyeing with medium/dark colors - Exhaust dyeing at 80 °C
H-dyes (Hot brand)	Monochlorotriazinyl	- Suitable for printing on viscose rayon and cellulosic fibers - Dyeing at 100 - 105 °C
M-dyes (Cold brand)	Dichlorotriazinyl	- Suitable for cellulosic fibers - Exhaust dyeing at 35 °C

In textile manufacturing, reactive dyes are preferred due to their generally high light-fastness ratio and their stability under sunlight. In general, reactive dyes' affinity for cellulosic material is below the required level. Therefore, salt addition is necessary

to increase the affinity. Additionally, reactive dyeing can be performed only under certain temperatures, ranging between 40 °C-80 °C, and pH. These properties make reactive dyeing wastewaters difficult to handle (Chakraborty, 2014).

2.1.4.1 Commonly Used Machineries for Reactive Dyeing

In the textile industry, both the methods and the machinery used for the dyeing process are tailored to the particular kind of material being dyed. Cotton is the most common textile substrate, and woven fabric is the most common material form for dyeing. In light of this fact, the methods and equipment used in dyeing cotton-woven fabric are of the utmost significance.

The mode of dyeing, batch, semi-continuous, or continuous, and the form of the substrate, which can be open-width or rope, are also factors influencing the machinery choice for cotton-woven fabrics (Clark, 2011a).

In reactive dyeing of woven cotton fabrics in open-width form, jiggers are commonly used for the operation in batch dyeing mode (Chakraborty, 2014). In the jigger dyeing machine, fabric in open-width form is repeatedly passed from one roller to another and goes through the dyebath each time. In this equipment, the tub remains motionless while the fabric moves. While the fabric is being rotated on the rollers, the dye liquor penetrates the material. One turn refers to the movement of fabric from one roller to the next, and there are several turns in the dyeing process (Clark, 2011a; European Commission, 2022). In Figure 2.4, a cross-sectional view of the jigger is represented.

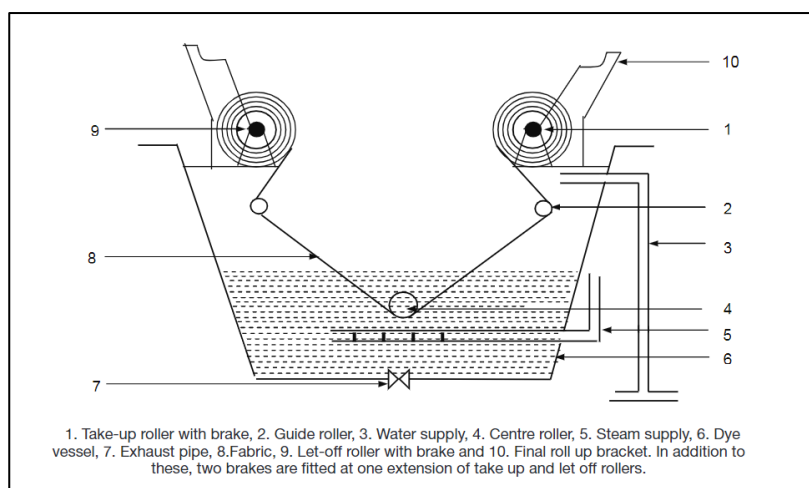


Figure 2.4. Jigger Dyeing Machine (Chakraborty, 2014)

Using padding machines for dyeing open-width fabrics in continuous mode is a common practice in the textile industry. In these machines, the dye liquor is absorbed by the fabric as it moves through the pad, then it is compressed between rubber rolls. The liquor pick-up ratio depends on how much pressure is applied by the rolls, the type of textile material, and the transfer speed of the fabric. Padding methods employ the usage of urea in contrast to other reactive dyeing methods. In reactive dyeing, the pad-steam process, which is one of the padding methods, is widely applied. Pad-steam dyeing starts with the application of dye by padding and then continues with intermediate drying to increase the liquor pick-up. Subsequent padding of the cloth with developing agents follows these steps, and dye fixation is achieved at a temperature of about 100 °C with steaming. Finally, the dyeing application is finalized by washing and rinsing steps. In Figure 2.5, a cross-sectional view of a padding machine is represented.

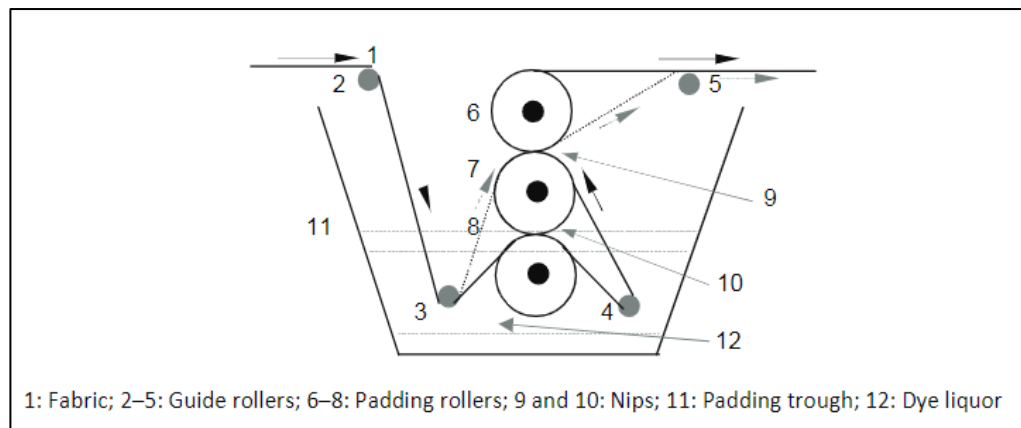


Figure 2.5. Padding Machine (Chakraborty, 2014)

For the textile materials in rope form, dyeing is operated in batch mode, generally with jet dyeing machines. In jet dyeing, the fabric is positioned inside of an enclosed tube system and transported through the tube with the driving force of the jet of dye liquor. The turbulence makes it easier for the dye to penetrate the fabric and keeps it from coming into contact with the tube's sides. It is necessary to use a relatively small amount of dye bath since it is regularly subjected to high liquor concentrations within the tube (European Commission, 2022). Figure 2.6 represents a cross-sectional view and parts of a jet machine.

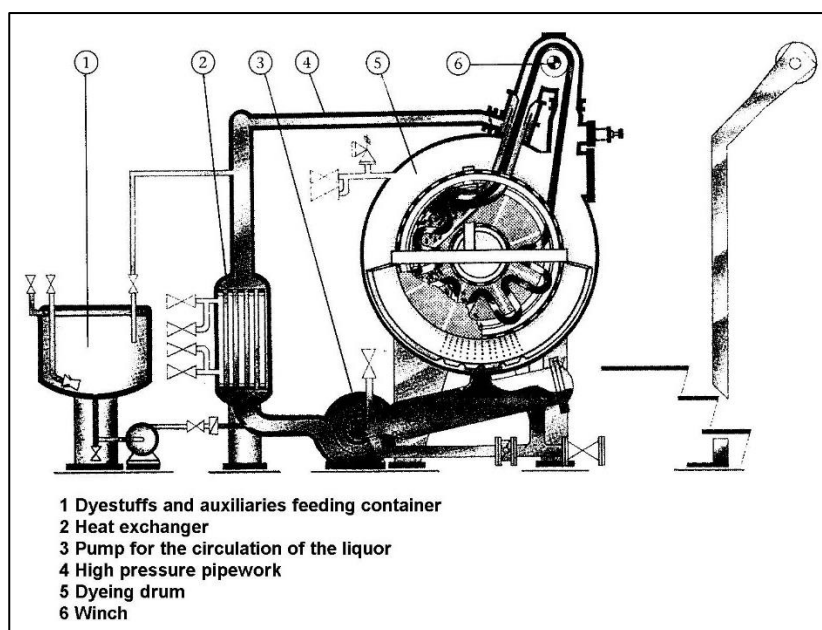


Figure 2.6. Jet Dyeing Machine (European Commission, 2022)

2.2 REACTIVE DYEING WASTEWATER

The textile dyeing process uses substantial quantities of water and results in the generation of a significant amount of wastewater as a result of the stages involved in both the dyeing and finishing processes. The wastewater from reactive dyeing is characterized by high color intensity due to unfixed dyes, high COD concentration, high salt and pH content (Erkanlı et al., 2017). The environmental issues emerging from the dyeing wastewater are highly dependent on the color, toxicity, and metal content of dyes, auxiliaries used in the dye recipe, such as salts, alkali, oxidizing and reducing agents and dispersants. Therefore, it is evident that the characteristics of the dyeing wastewater are determined by the dyeing recipe (European Commission, 2022).

2.2.1 Characterization of Reactive Dyeing Wastewater

During reactive dyeing, in order for dyes to form covalent bonds with the fiber, an alkaline pH condition, approximately pH 9.5 - 11.5, is required. For this purpose, sodium carbonate (Na_2CO_3) or sodium hydroxide (NaOH) is used. Since reactive dyes are classified as anionic dyes, fibers' negatively charged surface affinity to dyes is low. Sodium chloride (NaCl) or sodium sulfate (Na_2SO_4) salts are used to increase affinity, dye exhaustion, and fixation. The salt amount to be used depends on the dyeing method, affinity level of the dye, and shade depth. Since the fixation ratio of reactive dyes is poor, a significant amount of hydrolyzed dye remains in the dyebath (Khatri et al., 2015). Therefore, the wastewater from the dyeing, washing, and rinsing stages contains high concentrations of dye together with high salt concentrations. According to the class of the reactive dye, the dyeing temperature may rise up to 80 °C, which leads to the generation of high-temperature wastewater (European Commission, 2022).

Soap and urea are also two of the most important components used for reactive dyeing. Soap and surfactants are added to the wash water to remove any unfixed dye from the fabric after dyeing (European Commission, 2022). Urea is generally used in padding processes and is added to achieve the desired color of the dye. Urea is needed in greater quantities for darker colors, whereas lower amounts are sufficient for lighter colors (Erkanli, 2016). All chemicals used in reactive dyeing cause reactive dyeing wastewater, with a high temperature, to contain high color, pH, and high concentrations of salt, dissolved solids, Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) (Yaseen & Scholz, 2019).

Reactive dyeing wastewater may have various properties, and these properties change depending on the type of fiber and the chemicals used. The wastewater contains significant quantities of chemicals that harm both human health and the environment. Trace metals, such as zinc, chromium, copper, and arsenic, may also be found in the wastewater, all of which potentially harm the environment. The high color content of wastewater may also inhibit photosynthesis by blocking the sunlight

penetration from the water's surface. The dye content of the wastewater also increases the non-biodegradable organic matter content of the receiving water, resulting in the disruption of oxygen transfer process at the air-water interface due to the high concentrations of suspended solids (Ghaly et al., 2013).

As a result of the literature review done to determine the reactive dyeing wastewater characteristics, typical characteristics of reactive dyeing wastewater are tabulated and given in Table 2.3. When the wastewater characteristics from each step of reactive dyeing are analyzed, the highest values for each parameter were observed in the dyeing bath, and it was noticed that the concentration values decreased in each washing step, as predicted. In Table 2.4, wastewater characteristics from different stages of reactive dyeing are given.

Table 2.3. Characteristics of Reactive Dyeing Wastewater (Chollom et al., 2015; Yaseen & Scholz, 2019)

Parameters	Yaseen & Scholz, 2019									Chollom et al., 2015
	Carmen & Daniel, 2012	Savin & Butnaru, 2008	Almazán-Sánchez et al., 2016	Tomei et al., 2016	Buscio et al., 2015	Sun et al., 2014	Aouni et al., 2012	Nopkhuntod et al., 2011	Syafalni et al., 2012	
pH	5-10	6.3-10.7	6.84	8.5-9.5	6.9	7.4-7.9	7.11	-	-	10
Color (Pt-Co)	-	-	330	0.66±0.06	300			2,502,000±500	9-10.18	711
COD (mg/L)	1100-4600	258-1970.6	344.00	1017±58	806.00	1114-1350	708	45500±182	680-750	890
BOD (mg/L)	10-1800	70-300	91.91	9.8±1.3	-	-	-	5	298-360	
TOC (mg/L)	-	-	84.92	158±9.8	-	-	-	-	-	153
EC (µS/cm)	-	-	471.30	-	-	-	-	-	-	10000
TS (mg/L)	500-14100	-	-	-	-	-	-	-	-	-
TSS (mg/L)	-	72-956	-	-	112.00	-	-	45±0.73	0.0076	167
TDS (mg/L)	50.00	-	-	-	-	-	3137	-	-	-
Turbidity (NTU)	-	-	104.66	-	-	125-137	4.02	-	63-74	67
Chlorides (mg/L)	-	48-601	338.19	38.6±3.1	270.00	-	>125	-	-	-
Total Alkalinity	-	-	83.25	-	150.00	-	-	-	-	-

Table 2.3 (cont'd)

Parameters	Yaseen & Scholz, 2019									Chollom et al., 2015
	Carmen & Daniel, 2012	Savin & Butnaru, 2008	Almazán- Sánchez et al., 2016	Tomei et al., 2016	Buscio et al., 2015	Sun et al., 2014	Aouni et al., 2012	Nopkhuntod et al., 2011	Syafalni et al., 2012	
(mg/L as CaCO ₃)										
Total Hardness (mg/L as CaCO ₃)	-	-	119.17	-	50.00	-	-	-	-	-
NO ₂ (mg/L)	-	0.08–1.32		3.8±0.1	-	-	-	-	-	-
NO ₃ -N (mg/L)	-	3.7-8.3	1.90		-	-	-	-	-	-
NH ₄ /mg/L)	-	0.48–33.3		40.01±4.5	-	-	-	-	-	-
Mg (mg/L)	-	-	4.39	-	-	-	18.6	-	-	-
Fe (mg/L)	-	-	0.34	-	-	-	-	-	0.13–0.15	10

Table 2.4. Characteristics of the Wastewater from Different Stages of Reactive Dyeing (Erkanlı et al., 2017; Ghaly et al., 2013)

Parameters	Process Stages			
	Dyeing	Hot Rinsing	Soap Washing	Warm Rinsing
pH	9.5 ¹	9.4 ¹	7.7 ¹	7.7 ¹
	7-10 ²	7.5-8.5 ²	7.5-8.64 ²	7-7.8 ²
COD (mg/L)	1000-3000 ²	300-500 ²	50-100 ²	25-50 ²
BOD (mg/L)	400-1200 ²	100-100 ²	25-50 ²	-
TOC (mg/L)	543±8 ¹	333±7 ¹	80±3 ¹	44±2 ¹
EC (mS/cm)	64.9±0.1 ¹	39±0 ¹	6.6±0 ¹	1.7±0 ¹
Turbidity (NTU)	113±1.7 ¹	65±1.6 ¹	14.8±0.3 ¹	19.3±1.0 ¹
SAC (436/525/620 nm) (m ⁻¹)	292/429/68 ¹	196/334/43 ¹	29/21/9 ¹	43/77/7 ¹

¹Erkanlı et al., 2017

²Ghaly et al., 2013

2.2.2 Reactive Dyeing Wastewater Treatment and Reuse

The properties of reactive dyeing wastewaters, such as their high COD concentration, intense color, high temperature and pH, and poor biodegradability, cause them to pose major environmental and public health risks if they are not properly treated and discharged. The increasing variety of textile products necessitates the utilization of a wide range of dyestuffs, each of which possesses a different set of chemical properties. As a result, the treatment of textile wastewater becomes more challenging (Akçakoca Kumbasar & Ekmekci Körlü, 2016).

Depending on the intended treated effluent quality, the methods utilized to treat reactive dyeing wastewater differ. Whether the treated water will be discharged

directly to the receiving environment or reused is one of the issues determining the treatment methods. In addition, the discharge standards determined by the countries also play a decisive role in the selection of the treatment method (Khatri et al., 2015; Wang et al., 2011).

There are several treatment methods for reactive dye wastewaters. It is possible to classify these treatment methods into biological, physicochemical, physical (separation techniques and membrane filtration), and combined wastewater treatment processes. The use of physical or chemical treatment methods, followed by biological treatment, is a part of a combined treatment approach. This approach seeks to enhance the biodegradability of wastewater in order to facilitate its treatment via biological processes (Suresh, 2014).

Textile dyes have low biodegradability, which causes the treatment of dyeing wastewater by biological methods to be inefficient. Although sufficient COD removal can be achieved with biological treatment, the color content cannot be completely removed (Badani et al., 2009). Therefore, a combination of physicochemical treatment methods with biological treatment may be required to achieve the intended level of color removal, which results in higher treatment costs. In addition, long hydraulic retention time and sludge settling problems are well-known disadvantages of conventional biological treatment methods (Yang et al., 2020).

Coagulation-flocculation is one of the treatment methods classified under physicochemical treatments. It is possible to achieve the reduction of insoluble dye content from the wastewater to a certain extent. However, for soluble dyes, such as vat and reactive dyes, the efficiency of this treatment method is considered to be low (Holkar et al., 2016). The use of this method also has the disadvantage of high amounts of chemical sludge production. The generation of sludge results in substantial costs associated with treating the sludge and causes environmental concerns over the disposal of the sludge (Khatri et al., 2015).

Another physicochemical treatment method, adsorption with activated carbon, is found to be effective, especially for the removal of soluble dyes such as reactive dyes from the dyeing wastewater (Adane et al., 2021). However, the suspended solid content of the wastewater lead to rapid clogging, which causes the dyeing wastewater not to be treated directly with activated carbon adsorption (Wang et al., 2011). Adsorption is deemed to be effective when it is used in combination with coagulation-flocculation or biological treatment as a polishing step. The combination makes it possible to decrease the organic component and suspended solid content and enables the toning down of the color (Khatri et al., 2015). Additionally, the cost associated with the regeneration of activated carbon is considered to be the main disadvantage of the activated carbon adsorption method (Suresh, 2014).

One of the treatment methods is the advanced oxidation process (AOP), which is responsible for the production of sufficient numbers of hydroxyl radicals. Hydroxyl radicals are strong oxidizing agents, which enables them to interact with the majority of the dyes with high reaction rate constants (Holkar et al., 2016). However, the treatment efficiency of the chosen AOP is severely hindered by the ingredients of the dye bath, which are sodium salts, sequestering agents, wetting agents, and detergents, among other constituents (Alaton et al., 2002). Ozonation, Fenton's oxidation, and photo-oxidation methods, such as UV with hydrogen peroxide (UV/H₂O₂) and UV with titanium dioxide (UV/TiO₂) are the four types of AOP that have been extensively researched.

Usage of ozonation makes the rapid decolorization of dye molecules possible by breaking the conjugated double bonds. The total color and COD content that needs to be removed determines the dosage of ozone that should be applied to the dyeing wastewater. Other than dye content, dyeing wastewater often contains auxiliary materials reacting with ozone, resulting in an increased ozone requirement. As a result, wastewater may need to be pretreated before ozonation or should be applied in combination with other physicochemical or biological treatment methods to achieve an effective treatment (Suresh, 2014). The most significant drawback with the use of ozonation is the possibility of toxic by-product formation. Ozone gas

also has a short ten-minute half-life in water with a pH of 7, leading to costly operation (Adane et al., 2021). Additionally, the decomposition rate of ozone gas is dependent on the temperature, pH level, and salt content in the wastewater, and it decomposes quicker under conditions having a pH greater than 8.5. The treatment of textile wastewater by ozonation is considered to be problematic since it generally has a pH of 8 and above (Adane et al., 2021; Dasgupta et al., 2015).

Fenton's oxidation is another AOP used to remove the color from the wastewater. Although this method is cheaper than ozonation and provides effective COD and dye removal, chemical sludge is generated at the end of the process (Suresh, 2014). Photo-oxidation methods such as UV/H₂O₂ and UV/TiO₂ have the advantage of generating no sludge. However, the main drawbacks of photo-oxidation methods are high operational costs and the incapability of UV light to penetrate uniformly into color-containing wastewater (Suresh, 2014).

Electrochemical treatment methods are also applied to dyeing wastewaters to remove the color content and other pollutants. The dye degradation by electrochemical methods is occurred with direct oxidation on the anode by means of chloride usage and with indirect oxidation with the aid of species generated at the anode. In this method, chloride is used as the electrolyte, which is convenient as the reactive dyeing wastewater has high salt content obviating the need for external salt addition for electrochemical treatment (Buscio et al., 2016). Although this treatment method provides efficient removal of color and COD, it has a high operational cost associated with electrode consumption and precipitation handling problems (Riera-Torres et al., 2011; Wang et al., 2011).

As a result of the literature review on the treatment methods, it can be stated that although described treatment techniques offer several advantages in various aspects, they also have drawbacks, particularly in operational terms. In the current conditions, which necessitate minimizing the consumption of water, energy, and raw material, it is not sufficient to evaluate treatment methods solely based on their treatment efficiency and cost. Due to industrialization and the dramatic growth in the

population, water resources are rapidly depleted, which results in an increase in the cost of clean water. This situation has led to the need to use treatment systems integrated with the plant to sustain the plant's own water and raw material cycle instead of using end-of-pipe treatment methods (Allègre et al., 2006; Chollom et al., 2015). The use of membrane separation methods enables industries to reuse the wastewater by providing an effluent meeting the water reuse quality standards. The wastewater treatment by means of membrane separation is also deemed an efficient method for concentrating large volumes of wastewater into a relatively small volume for final disposal (Aouni et al., 2014).

2.2.3 Membrane Filtration

Membrane separation methods are based on the selective permeability of membranes depending on their different pore sizes and surface charges. The separation of the fine particles and dissolved solids from the stream is provided without changing the phase or properties of the chemicals (Pannirselvam et al., 2019). Membrane processes differ in terms of the driving force under action for the separation. Concentration or chemical potential difference, pressure difference, temperature, and electrical potential gradient are the driving forces applied to different membrane separation processes. In membrane processes for which the driving force is the pressure difference, constituents are separated from the wastewater based on the sizes of the molecules and the pore size of the membrane (Drioli & Giorno, 2016). In Figure 2.7, representation of a general membrane treatment system is demonstrated.

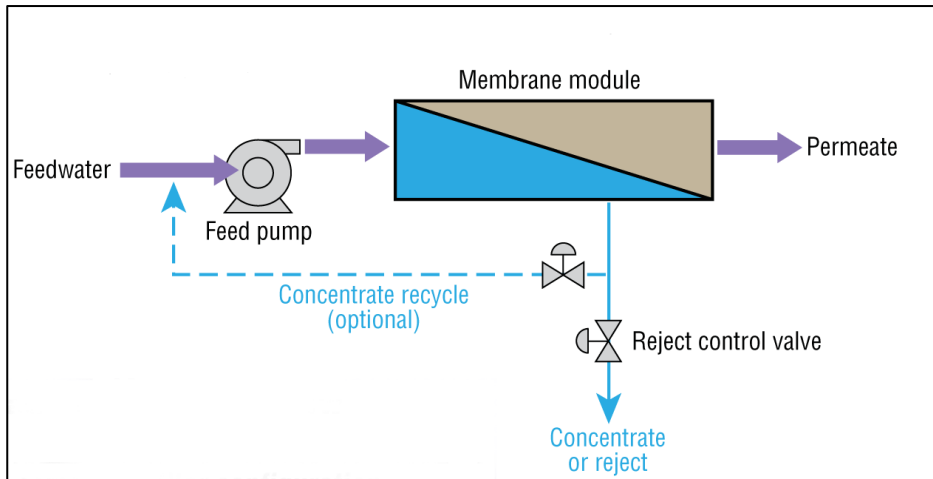


Figure 2.7. Representation of a Membrane Treatment System (Mukiibi & Feathers, 2009)

There are four main types of pressure-driven membrane processes that differ from each other in terms of their pore size and the applied pressure, which are Reverse Osmosis (RO), Nanofiltration (NF), Ultrafiltration (UF), and Microfiltration (MF) membrane applications. In Figure 2.8, the categorization of these membranes based on pore size and separated components is shown.

Membrane type	non-porous	micro-porous	meso-porous	porous			
Membrane process	reverse osmosis gas separation pervaporation		nanofiltration	ultrafiltration		microfiltration	
Pore or particle size	0.1 nm		1 nm	10 nm	0.1 μm	1 μm	10 μm
Separated components	gases vapors		sugars	proteins	viruses	bacteria	emulsions colloids

Figure 2.8. Membrane Classification based on Separated Components (Drioli & Giorno, 2016)

2.2.3.1 Microfiltration

MF with a pore size of 0.1-10 μm is a suitable filtration treatment for removing suspended solids and pigments from the dyeing and rinsing baths (Wang et al., 2011). However, this membrane filtration method is not capable of removing auxiliary chemicals and dissolved solids (Gürses et al., 2020). Therefore, in the literature, MF is suggested to be used as a pretreatment for RO or NF (Babu et al., 2007).

2.2.3.2 Ultrafiltration

It is acknowledged that UF with a pore size ranging from 1 nm to 0.05 μm is appropriate for the removal of particles and macromolecules. In this membrane process, it is also possible to achieve the removal of dyes to a certain extent (Wang et al., 2011). Complete removal of dyes depends on the pore tightness of the selected UF module (Jiang et al., 2018).

2.2.3.3 Nanofiltration

NF membrane elements have pore sizes ranging from 1 to 10 nm. NF membranes provide more than 99% rejection for multivalent ions, approximately 70% for monovalent ions, and more than 90% for organic compounds (Nagy, 2019). NF is accepted to be suitable for the efficient removal of hydrolyzed dyes and other auxiliary chemicals to the level at which reuse standards are met. As NF membranes have very small micropore sizes, this membrane application can also remove large monovalent and divalent ions and compounds with low molecular weights (Allègre et al., 2006). NF can efficiently be used as a single-step treatment method for dyeing wastewater treatment (Wang et al., 2011).

2.2.3.4 Reverse Osmosis

RO applications provide the complete removal of unfixed dyes and dyeing auxiliary chemicals. More than 90% of the rejection rate can be achieved with RO. Therefore, the treatment of reactive dyeing wastewater can be achieved in a single step (Babu et al., 2007). However, as the concentration of dissolved salt increases in reactive dyeing wastewater, the efficiency of RO decreases due to the drop in osmotic pressure. Correspondingly, in order to achieve the desired removal levels, transmembrane pressure should be increased, which results in higher energy requirements (Babu et al., 2007).

2.3 INTEGRATED POLLUTION PREVENTION AND CONTROL

The significant increase in human activities since the beginning of the industrial revolution has resulted in the consumption of vast quantities of resources and energy in a comparatively short time frame. High-rate consumption of non-renewable resources and mass production have substantial adverse impacts on the environment due to the pollution of all environmental compartments (Nowosielski et al., 2007).

Industrial growth, while inevitable and vital, especially for developing countries, has certain adverse effects on the environment, particularly in underdeveloped countries. The Industrial Revolution in 1750 is held responsible for many environmental problems arising from industrial activities, as well as for Climate Change. Compared to the beginning of the industrial period, current greenhouse gas concentrations are found to be substantially higher (Ahmed et al., 2022). It is certain that the growth in the economy and environmental conditions are interconnected. Production and consumption activities are closely linked to the environment in which they take place. Consequently, when the economy develops, its environmental impact increases and irreversible consequences of this cumulative economic growth on the non-renewable resources create an imbalanced relationship between the economic growth and the environment (Kahuthu, 2006).

Controlling pollution after it has already been produced has often been the primary focus of environmental protection efforts in the past. This waste management approach has certain drawbacks, despite the fact that it can preserve both human health and the environment. Instead of solving the pollution issue, this approach only shifts the pollution from one environmental compartment to another, with no net positive impact on the environment.

Traditional waste management requires treatment equipment, resources, and energy that would not be needed if waste is not produced. Pollution prevention is centered on minimizing waste rather than establishing end-of-pipe advanced treatment systems to ensure waste poses no hazard to the environment and human health. The overall approach to waste management in developed countries has started to change from pollution control-based activities to pollution prevention as a result of the increasing recognition of the gains of waste prevention (Dupont et al., 2017).

According to Ozturk et al. (2016), pollution prevention can also be defined as "cleaner production". Environmental efficiency and sustainable production fall under the umbrella of cleaner production. In 1989, United Nations Environment Programme (UNEP) established the "Cleaner Production" concept addressing sustainable environmental management and resource conservation. This environmental management approach, which focuses on the prevention and/or reduction of waste before it is generated, aims to minimize overall pollution and increase resource use efficiency (UNEP, 2001).

As the application of the cleaner production approach not only preserve the environment but also provide improvement in technical performances and economic gains to industries, in many countries, particularly in the European Union (EU), pollution prevention measures have gained prominence and have been included in environmental regulations (Simsek et al., 2022). In accordance, the Integrated Pollution Prevention and Control (IPPC) Directive was published in 1996.

The integrated waste management approach and the use of Best Available Techniques (BAT) are the two pillars of the IPPC Directive. Environmental benefit

and cost balance can be achieved by using BATs in the protection of the environment. BATs are developed and described for different sectors for the production processes, waste management, and disposal. The Sectoral BAT Reference Documents (BREFs) have been developed to enable the businesses to comply with the IPPC directive. In 2010, the Industrial Emissions Directive (IED-2010/75/EU) took the place of the IPPC Directive. The IED has been prepared and published to cover seven previously published directives, including the IPPC Directive (Ozturk et al., 2016).

The primary goal of the IED is to attain a high degree of environmental protection through the prevention and control of emissions with an integrated approach (European Commission, 2010). In the IED, BREF documents for each sector define the BATs and environmental and economic performances of these applications. The BATs are not developed to be prescriptive; they aim to provide assistance in evaluating the efficiency of installations (Evrard et al., 2016).

BREFs are composed of general information about the sector, applied processes and techniques, emission and consumption levels, techniques to consider in the determination of BATs, BAT conclusions, and emerging techniques. Among these headings, BAT Conclusions have specific importance as it is also published in the EU Official Journal and are legally binding for the Member States. After the publication of the IED, the impact of BATs in the industry and the importance of their implementation increased. The establishment of emission limit values (ELV) in accordance with BAT-associated emission limits (BAT-AEL) has become a requirement for the issuance of permits for industrial plants in the Member States, and this requirement came into effect with the publication of the IED (Ozturk et al., 2016).

As is the case for each sector included in Annex-1 Sections 6.2 and 6.3 of IED, the BREF for the textile industry offers various application alternatives for process modifications, emission prevention and control, efficient use of resources, and raw materials, along with methods for reuse, recycle and recovery. All these suggested

applications provide considerable savings in terms of raw materials, energy, and water without affecting the quality of the textile product (Dogan et al., 2010). Recovery of reactive dyeing wastewater with high salt concentration is among the main issues addressed by the Textile Industry BREF (European Commission, 2022). For reuse and/or recycling of dyeing process baths, the use of membrane filtration applications such as MF, UF, NF, and RO is suggested in the Textile Industry BREF (European Commission, 2022).

2.4 LIFE CYCLE ASSESSMENT

LCA is an approach followed to determine, evaluate, and manage the environmental impact of a product, process, or service associated with its complete life cycle. The life cycle of a product is defined as the production, usage, and end-of-life stages, which are interconnected and follow each other, from raw material procurement to disposal. The environmental impacts of a product over the course of its life cycle may stem from the energy, chemical, raw material, and water consumption and emissions to all environmental compartments (Eryuruk, 2015). LCA tool enables decision makers to understand and evaluate the impacts of products and production processes on the environment and human health, enabling them to make more informed decisions (Dahllöf, 2004).

European Commission's aforementioned sectoral BREF documents are prepared and published to identify the BATs for various industries. These reference documents also serve as a guide for the implementation of BATs. However, the BREFs mostly provide a wide variety of BAT options, making it challenging to select the best one for a company based on various considerations. As a result, there is a need for approaches and tools that will assist industries in selecting BATs suitable for the operational conditions (Ibáñez-Forés et al., 2013). At this point, LCA is considered an important tool for evaluating and comparing the BATs described in BREF documents and selecting the most sustainable one among the BAT alternatives (Yilmaz et al., 2015).

The International Organization for Standardization (ISO) has developed a set of guidance standards on LCA, which are titled as 14040 series. These standard series provide direction for each stage of the LCA process. The LCA process is broken down into its component parts in this series of 14040. For the standardization of an LCA study, ISO 14040:2006 and ISO 14044:2006 core standards should be followed (Linhares & de Amorim, 2017). According to ISO 14040:2006, the LCA methodology is comprising of four consecutive steps as listed below (Linhares & de Amorim, 2017; Muralikrishna & Manickam, 2017):

- **Goal and Scope Definition:** In this stage, the context of the LCA study is determined. System boundaries, functional units, product systems, and assumptions and limitations are also defined under the scope of goal and scope definition.
- **Life Cycle Inventory (LCI):** In this stage, raw material, water, and energy inputs, in addition to the emission outputs, are determined, and mass balance on these parameters is conducted. All inputs and outputs within the system boundaries are also defined both in quality and quantity.
- **Life Cycle Impact Assessment (LCIA):** The outcomes of LCI form a base for the LCIA stage. In this stage, impact categories and indicators are selected. Subsequently, the assignment of LCI outcomes to impact categories is done. Finally, characterization, normalization, and weighting steps finalize the studies in this stage.
- **Interpretation:** In the final stage, the results of LCI and LCIA studies are evaluated on the basis of sensitivity and consistency; and the final results are presented.

The LCA framework, including the four stages listed, is given in Figure 2.9.

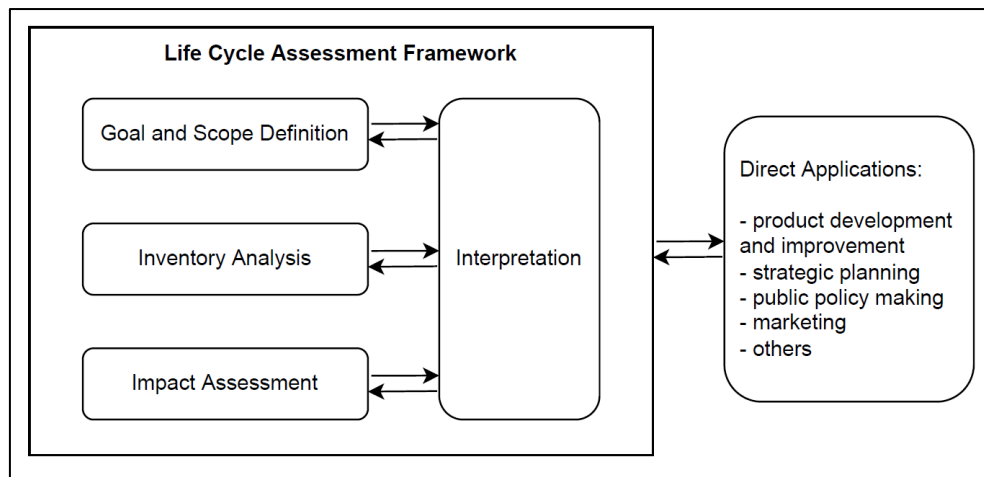


Figure 2.9. LCA Framework (Muralikrishna & Manickam, 2017)

According to the ISO Standards, LCA is a technique that is recognized and used all over the world for the purpose of collecting and assessing the inputs and outputs as well as the possible environmental consequences of a product system during its entire life cycle (International Organization for Standardization, 2006b).

2.4.1 Life Cycle Assessment Stages

2.4.1.1 Goal and Scope Definition

The objective, scope, and methodology are clearly defined at this first stage of LCA. The goal definition stage includes determining the purpose for conducting the study as well as the purpose for which the results of the LCA study will be used (Guinée, 2002).

Description of the methodological approaches, assumptions, and limitations forms the basis of the scope definition study. The scope of the LCA is defined to ensure that both the breadth and the level of depth of the study are consistent with and adequate for the predetermined purpose. At this stage, the system boundaries and the associated functional unit are clearly determined. The functional unit is the reference unit to scale the product system in accordance with the functions provided. Defining

a functional unit is necessary to establish a relationship between inputs and outputs. This relationship is required in order to make it possible to compare LCA results. Material and energy flows should be defined per functional unit (Cooper, 2003). In the case of reactive textile dyeing, the functional unit can be defined as "per ton of fabric dyed".

Under the goal and scope definition stage, system boundaries are defined by determining the unit processes to be included as inputs, outputs, and basic flows. The system boundaries may include processes and operations from raw material acquisition to disposal. Inputs and outputs within the system boundaries should be defined as elementary flows. The elementary flows are described as the interchange between the environment and the system for which the LCA study is performed. Typical elements of a system can be listed as raw material acquisition, transportation, manufacturing, energy consumption, use, disposal, recycling, and reuse (Sonnemann et al., 2019). According to the extent of the system boundaries, the LCA study can be classified as cradle-to-grave, cradle-to-gate, and gate-to-gate. If the life cycle boundaries are determined from raw material extraction to final disposal, this assessment is defined as cradle-to-grave. In this approach, all inputs and outputs of all life cycle stages are considered. The cradle-to-gate system is considered the partial life cycle assessment as the system boundaries do not include the end-of-life phase of the life cycle. As can be seen in Figure 2.10, the end of each life cycle stage is defined as a "gate". Therefore, the boundaries of a gate-to-gate assessment include the stages between two gates of the life cycle.

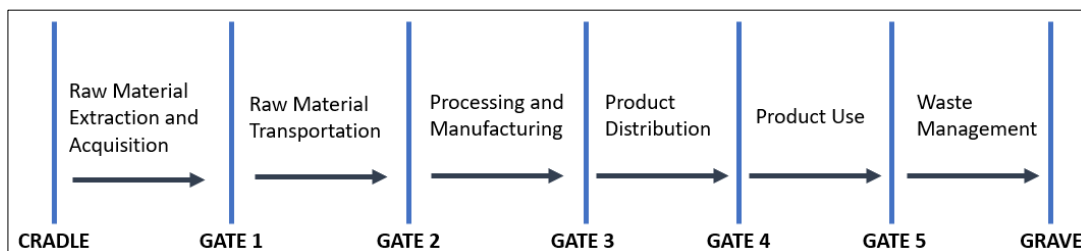


Figure 2.10. Life-cycle Stages (Sonnemann et al., 2019)

The final results of an LCA study are strongly correlated to the data used in the study. In this context, it is important to consider the indicators showing the quality of data, such as reproducibility, accuracy, representability, completeness, and consistency.

2.4.1.2 Life Cycle Inventory (LCI)

Life cycle inventory analysis is the quantification of water, energy, and raw material inputs, solid wastes, air emissions, water emissions, and other emissions along the life cycle of a product, process, or service. The inventory analysis phase involves the collection of data to calculate the relevant inputs (raw materials, water, energy, etc.) and outputs (emissions). It is not possible to evaluate comparable environmental impacts or prospective improvements without the LCI study. Following the determination and quantification of all the material flows, demonstration of the system should be done with a process flow scheme, showing the predetermined system boundaries. To exemplify, the process flow scheme of the textile production with system boundaries and related inputs and outputs are shown in Figure 2.11.

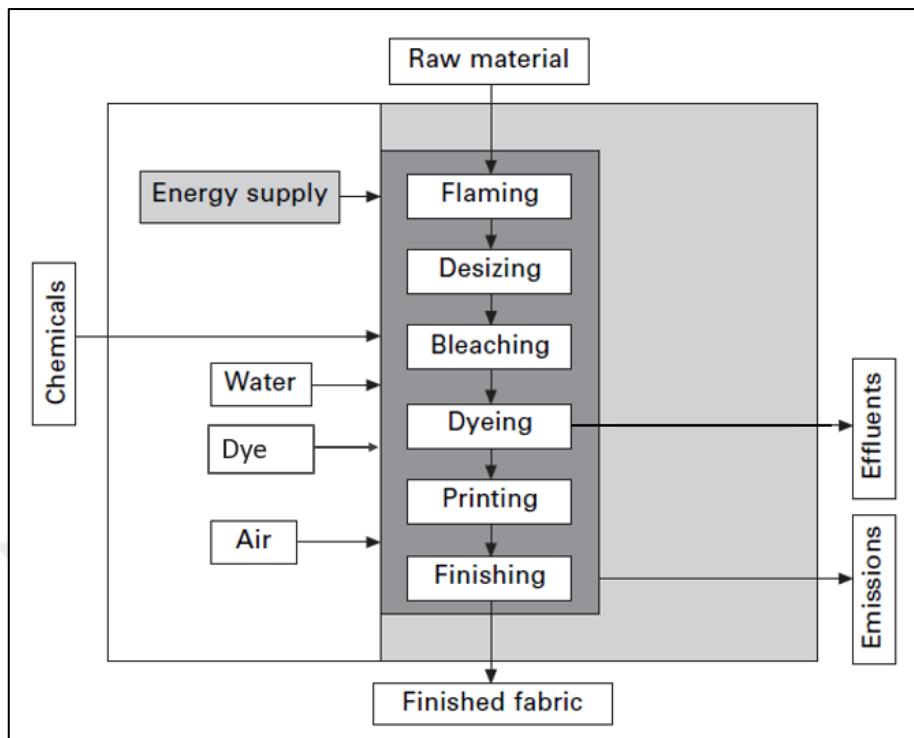


Figure 2.11. Representative System Boundaries, Inputs and Outputs (Tobler-Rohr, 2011)

The degree of precision and the extent of the gathered data significantly affect the rest of the LCA study and the results. Inventory analysis is an iterative process. At the end of the inventory analysis work, new data requirements or constraints can be redefined to achieve the targeted objectives.

LCI analyses have several applications. They can aid an organization in making comparisons for products or processes and selection of materials with environmental issues that are associated. Furthermore, inventory analyses can assist the government in policy-making by addressing resource consumption and environmental pollution. An LCI study generates a list of the amounts of emissions to the environment as well as the quantities (Curran, 2006).

2.4.1.3 Life Cycle Impact Assessment (LCIA)

LCIA is the stage where the findings concerning the extent of the environmental impacts are determined. At this stage, the goal is to assess the life cycle impacts in order to comprehend the product's or service's significance to the environment. Environmental impacts are classified, prioritized, and grouped under impact categories such as human health, global warming, and aquatic toxicity impacts. The sustainability of any product can be evaluated in terms of a single score, as well as in terms of CO₂ emissions.

According to ISO 14044, there are key elements that an LCIA study should include, and these elements are classified as "mandatory" and "optional". In Figure 2.12, the key elements are shown according to their categories.

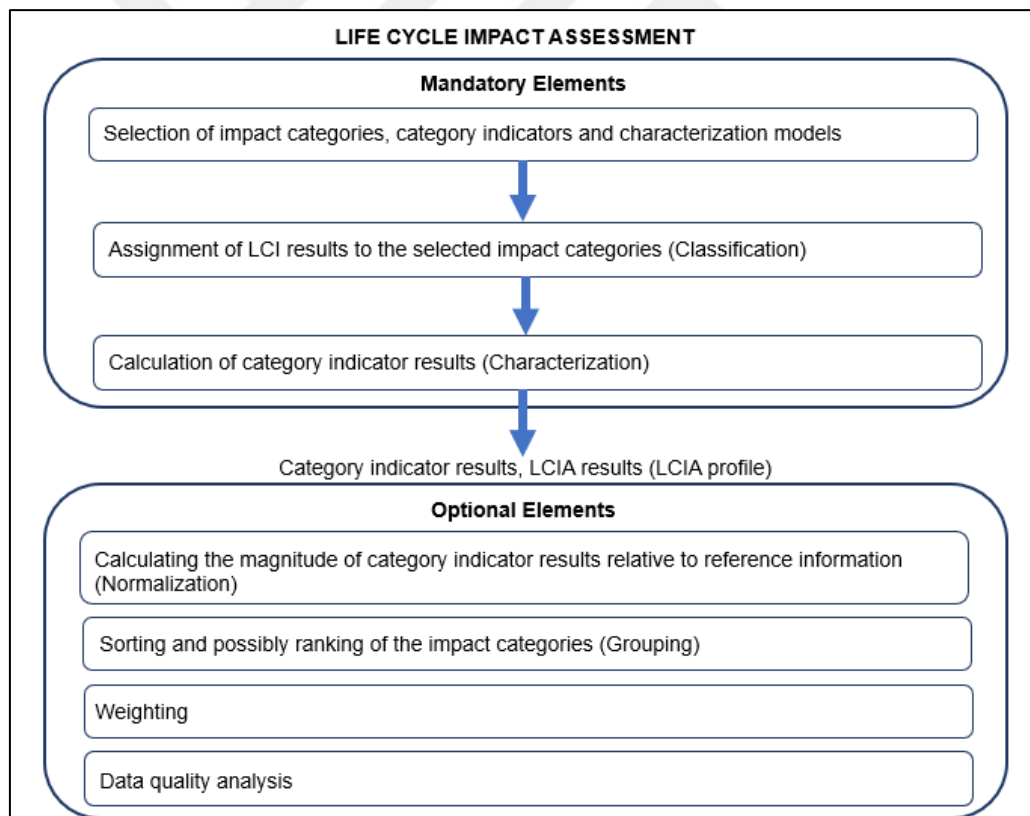


Figure 2.12. LCIA Key Elements (International Organization for Standardization, 2006a)

The mandatory elements convert the results of the LCI into the outcomes of the indicators. The mandatory elements are the “selection of impact categories, category indicators, and characterization methods”, as well as “classification” and “characterization”. In accordance with the goal and scope of the study, it is determined if the optional elements will be used. These optional elements include the normalization, grouping, and weighting of the indicator values, in addition to the analysis of the data quality. A baseline is established by normalization to facilitate comparisons between different environmental impact categories with the same unit. The output of the normalization step serves as an input for the subsequent steps of grouping or weighting. The results of the many impact categories are sorted and ranked as part of the grouping stage. A ranking of such can assist in arriving at judgments regarding the relative relevance of various impact categories. Within an LCA study, the relative importance of various impact categories can be determined through the "weighting" stage. Each impact category is assigned a weighted factor in this stage. In the "Normalization and Weighting" processes carried out after the calculation of the impacts, the different environmental impact categories are compared, and a single impact score is determined by allocating a weighting factor to the impact categories based on their relative importance.

There are several methods for life cycle impact assessment. These methods differ in the categories of impact they consider and use different factors in calculating impacts. Impact assessment can be made in terms of end-point indicators as well as mid-point indicators. “Mid-points” are regarded as a point in the cause-impact chain of a given impact category, between the LCI results and the “end-point” (Bare et al., 2000). End-point characterization indicators reflect the level of impact in categories such as ecosystem quality, human health, and scarcity of resources. These two different characterization methods are, in fact, complementary to each other. The mid-point method provides a stronger link to environmental flows, whilst there is less uncertainty in the indicators as the assumptions are minimized in this method (Curran, 2006). In end-point characterization, on the other hand, it is much easier to

understand and interpret indicators due to the clear connections with environmental flows (Huijbregts et al., 2017).

The impact categories are generated with the inventory analysis data. This categorization is accomplished by incorporating data from the inventory analysis into different impact categories. The purpose of the LCIA is to analyze the product system with the aid of impact categories and category indicators that are linked to the LCI results (Ölmez, 2011). Figure 2.13 represents the mid-point and end-point impact categories included in the ReCiPe2016 impact assessment method and their relation.

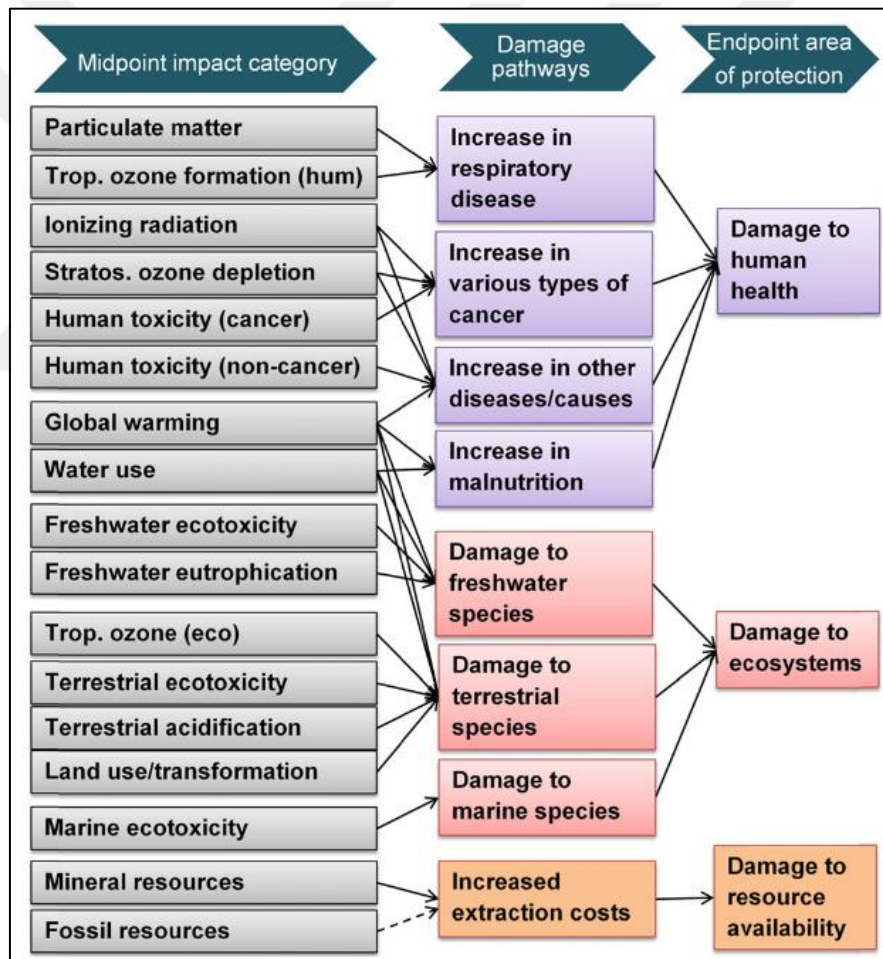


Figure 2.13. Mid-point and End-point Impact Categories of ReCiPe2016 Impact Assessment Method (Huijbregts et al., 2017)

2.4.1.4 Interpretation

Interpretation is a stage in which the LCA study is interpreted by considering the outcomes of the LCI and the LCIA stages together. At this stage, LCA results are evaluated with reference to the previously determined study goal and scope.

Sensitivity analysis is conducted to determine the impacts of alterations in the data and methodological choices on the assessment results. In LCA studies, sensitivity analysis may be required to evaluate the effects of importance determination methods on environmental impact assessment results since different importance determination methods are used in revealing environmental impacts. In addition, while controlling the data sensitivity, the data that affects the results the most can be determined, and how any change in these data values will affect the results can be analyzed.

However, the effects of input uncertainties and data variability should also be considered in LCA studies. Uncertainty analysis is an analysis method used for uncertainty calculation that arises in the LCI results due to the combined impact of input imprecision and data variability.

CHAPTER 3

LITERATURE REVIEW

3.1 Literature Review on the Membrane Treatment of Reactive Dyeing Wastewater

A comprehensive literature review on membrane applications in textile dyeing wastewater treatment is done, and it is deduced that removal of unfixed dyes and salts with membrane applications is possible, owing to the membrane's micropores. According to the studies on textile dyeing wastewater treatment with membrane applications, dye removal from the wastewater can be achieved while allowing the passage of salt content in the wastewater. Therefore, the salt-containing permeate obtained from membrane filtration can be recycled back to the beginning of the reactive dyeing process, which will allow a reduction in the consumption of water and salt and the production of wastewater with high salt concentration (Wang et al., 2011).

Chollom et al. (2015) studied combined UF and NF application for the reuse of reactive dyeing dye bath wastewater. The study was conducted in two stages. In the first stage, a UF membrane was used for the pretreatment; in the second stage, two different NF elements (SR90 and NF90) were used to reuse the wastewater, and the performances of these two NF membranes were compared. UF pretreatment showed no salt rejection with a dye removal percentage of 7-35%. 20-50% of salt rejection is obtained with SR90 NF element, which allowed a higher salt recovery in the permeate compared to NF90. As the NF90 element is a tighter membrane, the salt rejection percentage is found as 65-90%. Although both SR90 and NF90 membranes provided more than 90% dye rejection, the permeate from N90 was closer to the reuse standards. The results of the reuse tests showed that the permeated from both of the NF membranes could be reused for the dyeing of light shades, while the

permeates from the treatment of darker shades could only be reused for the dyeing of dark shades, as they do not meet the standards for light shade dyeing (Chollom et al., 2015).

In a study conducted with three different reactive dyes, the treatment performances of UF membranes with 10 kDa and 1 kDa; and NF200 and NF270 membranes were evaluated. While more than 80% of COD removal is achieved with both UF 10 kDa and 1 kDa membranes, total color removal was obtained only with UF 1 kDa membrane. NF200 and NF270 membranes provided color removal of more than 90% for all three reactive dyes. Although the use of UF 1 kDa membrane gives satisfactory results in terms of COD and color removal, it has been stated that direct UF application is insufficient in cases where conductivity removal is also aimed. Therefore, in this study, it is suggested that the use of UF should be applied as a pretreatment stage before NF (Aouni et al., 2012).

Jiang et al. (2018) studied the dye/salt fractionation performances of seven different pore-sized UF membranes. The experiments were conducted with four different dyes (direct red 23, direct red 80, reactive blue 2, and reactive orange 16) and salt concentrations of 0 to 60 g/L. UF membranes provided color removal of more than 99% even with a 60 g/L salt concentration for direct red 23, direct red 80, and reactive blue 2 dyes. However, the results of the experiments conducted with reactive orange 16 showed that as the salt concentration increased, the removal efficiency of the membrane decreased by approximately 50%. These outcomes indicate that by reducing the electrostatic repulsion of reactive dyes, salts are reducing the rejection efficiency of reactive dyes (Jiang et al., 2018).

The study conducted by Erkanlı et al. (2017), aimed to investigate the performances of UF membranes with 2 kDa and 5 kDa pore sizes. For this purpose, three scenarios were established as 5 kDa+5 kDa, 5 kDa+2 kDa and 2 kDa+2 kDa. The best Total Organic Carbon (TOC) and color removal was achieved in 2 kDa+2 kDa scenario, while a higher average flux was observed in 5 kDa+2 kDa scenario. Among these three scenarios, the worst performance was observed in 5 kDa+5 kDa

application with lower TOC and color removal. The study suggests that with the application of 2 kDa+2 kDa UF membrane system, the dyeing wastewater can be decolorized, and TOC removal can be achieved with no salt rejection. This application allows the colorless, brackish permeate to be reused in the dyeing processes (Erkanlı et al., 2017).

Fersi and Dhabbi (2008) analyzed the NF application and combined UF+NF application for the treatment and reuse of textile wastewater. It has been found that removal of color by 90%–95% and a decrease in conductivity by 45–70% can be achieved using direct NF. The UF+NF combination resulted in an increase in color and conductivity removal percentages. In addition to this, permeate flux of the combined UF+NF system was found to be more stable than that of direct NF. Combining the system with UF provides a progressive flux decline, which is rapid for direct NF application. Therefore, it is suggested to use UF as a pretreatment process before NF, as this application increases the run time of the membrane and the treatment efficiency (Fersi & Dhahbi, 2008).

In the study conducted by Lin et al. (2015), the main focus was on the dye rejection from dyeing wastewaters with NF membranes, while salt content aimed to be preserved in the permeate water. Two NF membranes were tested, and both were found to have a salt removal of approximately 33%, with NaCl concentrations ranging from 0.1 to 40 g/L. Furthermore, despite the presence of 40 g/L NaCl, both membranes retain more than 99.6% of the direct dyes, suggesting that higher salt concentrations do not exert any noticeable effect on the dye removal performance of membranes. The results of another study by Lin et al. (2016), which aimed to investigate the dye and salt separation from the textile effluent with a tight UF module, showed that tight UF membranes might be used to separate and recover salts and dyes effectively.

3.2 Literature Review on Reactive Dyeing LCA Studies

The textile industry is one of the key actors in the global economy. However, in terms of its environmental impacts, the textile industry is regarded as one of the most polluting sectors in the global economy. The sector is characterized by its high raw material, hazardous chemical, energy, and water consumption, which generates a significant amount of emissions to all environmental compartments, particularly a high volume of wastewater with a high level of pollution (Choudhury, 2014). The contribution of textile production to environmental pollution has led to the need to determine its environmental impacts qualitatively and quantitatively. LCA methodology is frequently used in studies in order to determine the environmental impacts and problematic stages of textile manufacturing, which are called as “hot spots”, as well as to optimize the production processes in the light of the LCA study results (Kazan et al., 2020). As the dyeing process is one of the primary sources of wastewater with a significant pollutant load, numerous LCA studies on the dying process, particularly reactive dyeing, can be found in the literature.

Zhang et al. (2015) carried out an LCA study in China to identify the environmental impacts of the cotton T-shirts' cradle-to-grave life cycle and to investigate the potential process improvements. The system boundary of the study includes all the stages from cotton production to disposal of textile products, including the reactive dyeing stage. The functional unit was determined as one T-shirt piece of 0.153 kg. For the impact assessment, CML2001 and USEtox methods were used via GaBi software in the study. The study results show that the hot spots of textile manufacturing are the energy, water, dye, and auxiliary consumption in the reactive dyeing process. According to the outcomes of the impact assessment, the reactive dyeing process has the highest contribution to abiotic depletion-elements (ADP elements), abiotic depletion-fossil (ADP fossil), human toxicity potential-cancer (HTPC), and water use (WU) impact categories.

In another study, Yuan et al. (2013) conducted an LCA study for the continuous pad-dyeing application on cotton textile materials. Raw material acquisition, production

and transportation of energy, dyeing, and disposal stages are included in the system boundary. The dyeing stage consists of pretreatment, pad-dyeing, and finishing sub-stages, which are all called wet processes. The study aims to determine the issues that have the greatest environmental impacts in wet processing and develop possible cleaner production proposals that focus on wet textile processing hot spots. According to the results of the study, it was determined that the categories with the largest share among all impact categories were global warming potential (GWP), eutrophication potential (EP), photochemical ozone creation potential (POCP), and acidification potential (AP). It was observed that the impact category that reactive dyeing contributed the most was EP, which is related to the high COD content of the dyeing wastewater. For clean production practices, the authors proposed process water recycling together with the controlled consumption of dyes and related auxiliary chemicals.

In their study, Zhang et al. (2018) aimed to improve the textile manufacturing process design in terms of environmental and economic aspects. For this purpose, a three-staged methodology was followed based on the LCA approach. In the first stage, the environmental impacts and points of concern associated with cotton fabric production and textile dyeing, printing, and disposal stages were assessed. For the impact assessment, the CML2001 method was used via GaBi software. The results showed that the printing and dyeing stage holds the highest percentage in each environmental impact category. In the second stage of the study, six different best available technology (BAT) options were developed, including a BAT related to reactive dyeing with low/no salt addition. In the third stage, the impacts of the application of proposed BATs were evaluated by means of an LCA study, and the results were compared with the business-as-usual operation. Findings from the study showed that the application of all six BATs demonstrated improvements in economic and environmental terms. More than 50% reduction was observed in ecological impact and resource depletion impact categories. Additionally, the application of reactive dyeing with low/no salt addition BAT saved 19,800 tons of steam and 65,900 tons of water annually.

In their LCA study, Murugesh & Selvadass (2013) focused on comparing the environmental impacts of exhaust dyeing and cold-pad-batch dyeing, which are batch and semi-continuous dyeing methods, respectively. In this study, three different reactive dye recipes were also studied in order to reveal the differences in environmental impacts of dyeing with different colors. While S1 (stone color) and S2 (blue color) fabric samples were dyed with the exhaust dyeing method, the S3 (red color) sample was dyed with cold-pad-batch dyeing. The inventory created based on these dyeing tests was evaluated by using SimaPro software. For the impact assessment of this cradle-to-grave study, the IMPACT 2002+ method was used. The study results show that the biggest share of the issues that contribute to the environmental impacts in reactive dyeing processes belongs to the use of dyes and auxiliary chemicals, water consumption, and energy consumption for steam production. The results also showed that the environmental impacts of exhaust dyeing are significantly greater than the cold-pad-batch dyeing method, as there is much more water, energy, and auxiliary chemical consumption in exhaust dyeing. The complete elimination of the use of salt in cold-pad-batch dyeing and the much lower water and energy consumption resulted in a lower share in all environmental impact categories. Additionally, a significant increase in the impact categories was observed when dyeing with darker colors compared to lighter colors, as dyeing with darker colors requires more raw material use.

A non-profit organization, Cotton Incorporated, conducted a Global Cotton LCA in 2010, of which the most recent revision was published in 2016. Provision of reliable and up-to-date LCI data for worldwide cotton fiber and textile production is the major goal of this study, which will help LCAs correctly account for cotton's environmental impact. The LCA was conducted to determine and assess the environmental impacts of a t-shirt, a knit collared shirt, and a woven pants. In the study, environmental impacts of batch and continuous reactive dyeing were also compared. The system boundaries of the studies were determined as cradle-to-grave, and the functional unit was determined as 1,000 kg of the finished fabric. The life cycle impact assessment was carried out by using CML and USEtox methods

embedded in GaBi software. The results of the study demonstrated that the dyeing process contributed the most to Blue Water Consumption (BWC), Eutrophication potential (EP), Global warming potential (GWP), Primary energy demand (PED), and Abiotic depletion potential (ADP) impact categories. The contribution to these categories is higher for batch dyeing compared to continuous dyeing. The continuous dyeing process's contribution to the impact categories was decreased by more than 10% when compared to the batch dyeing contribution (Jewell, 2017).

A cradle-to-gate LCA of melange yarns was carried out by Liu et al. (2020) to determine of environmental impacts and hotspots of melange yarn manufacturing and investigate potential areas leading to improvements in environmental performance. The system boundary includes life cycle stages from raw material acquirement to spinning. The impact assessment was conducted by using the ReCiPe method, which is one of the methods present in GaBi software, was used. In parallel with the results of other LCA studies in the literature, the hotspots are determined as water, reactive dye, and auxiliary chemical consumption in the dyeing stage. Upon the determination of the hotspots, a sensitivity analysis was performed to estimate the effects of changes in the amount of inputs and outputs. In accordance with the sensitivity analysis results, the authors proposed using recycled water in the dyeing process, which would provide a 30% decrease in the freshwater ecotoxicity impact category.

The literature review showed that no LCA study had been conducted before on salt and water recovery through the membrane treatment of reactive dyeing wastewater. The lack of studies comparing the environmental impacts of membrane-based salt and water recovery applications with the environmental impacts of the "business-as-usual" case is also considered to be a major gap in the literature. It can be stated that this study fills this gap in the literature, as it studies the reuse of reactive dyeing wastewater with the LCA approach by focusing on the environmental impacts of membrane applications, whose only treatment performances of dyeing wastewater have been studied in the literature before.

CHAPTER 4

METHODOLOGY

4.1 Study Approach

This study aimed to evaluate the BATs described for reusing reactive dyeing wastewater in the Textile Industry BREF document through an LCA study with a cradle-to-grave approach. The LCA was conducted by following the four standard assessment stages: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation.

In this study, which focused on the reactive dyeing process of textile manufacturing, the system boundaries of this process were identified, and a comprehensive literature review was conducted to prepare an inventory of the inputs and outputs within the system boundaries. The literature review showed that the inventory data, particularly water consumption, significantly differ between different dyeing techniques. Therefore, three different commonly used dyeing techniques were included in the scope of this study. These dyeing techniques are jet dyeing, jigger dyeing, and continuous pad dyeing.

In the BREF document, membrane filtration applications are suggested for reusing dye bath wastewater. Therefore, three different membrane application scenarios, direct UF, direct NF, and UF+NF combination, were studied. Membrane scenarios were constructed by using Water Application Value Engine (WAVE) software which was developed by Dupont Water Solutions. The inventory data for membrane applications were gathered from the result reports of the simulations conducted with WAVE.

Following the determination of the goal and scope and the collection of input and output for reactive dyeing and membrane applications, LCA studies were conducted

by using SimaPro software version Ph.D. 9.2. The existing libraries in SimaPro were used for the input and output entry. Although the existing database in SimaPro was used for most of the raw materials, reactive dye data were not found in the database of SimaPro. Therefore, research on reactive dye chemical reactions, manufacturing, and mass balance was conducted. As a result of the literature review, reactive dye input data was defined manually as "Reactive Orange 12" and introduced to the database.

Reuse scenarios were evaluated by means of the LCA study for each selected reactive dyeing technique. The results were analyzed and compared to that of direct discharge of reactive dyeing wastewater to shed light on the impacts of wastewater reuse with the use of membrane applications. Therefore, it will be determined if reusing the dyeing wastewater in the textile dyeing process that is decolorized after the membrane applications would result in a net positive gain in terms of the environmental impacts. Reactive dyeing and membrane application scenarios, data collection studies, and the overall LCA approach are explained in the following sections.

4.2 Data Collection

In this LCA study, dyeing inventory data were based primarily on the reactive dyeing data provided by actively operating textile dyeing plants. As secondary data, reactive dyeing input and output values retrieved from the literature were used for the inventory. For membrane treatment scenarios, WAVE design simulation results were used rather than literature values. However, in order to ensure the accuracy and consistency of the results obtained from WAVE, the results were validated by comparing them with the literature values.

4.2.1 BESTÜ Project Data

A significant part of the raw data used in the creation of the reactive dyeing inventory consists of the textile plants operating in various regions of Turkey, whose environmental performance data were obtained within the scope of “Cleaner Production Applications in Certain Industries (BESTÜ)” Project. The specific resource usage and atmospheric emission values of the plants that include the reactive dyeing process were taken from the textile plants within the scope of the BESTÜ Project, and a total of 15 plants were examined during the LCI study. Operation details of these textile plants and the retrieved data are given in APPENDIX A.

4.2.2 Environmental Impact Assessment Reports of Textile Plants

Some of the raw data used in the inventory analysis consist of the production and consumption values in the Environmental Impact Assessment (EIA) Reports of six textile plants operating in Turkey, which are open to public access. The list of these textile plants and the reactive dyeing process method employed by the plants are given in Table 4.1. Operation details of these textile plants and the retrieved data are given in APPENDIX A.

Table 4.1 List of Textile Plants with EIA Reports

Textile Plant	Reactive Dyeing Method	Process Type
Bil-han Tekstil (Burçed Mühendislik, 2017)	Jet Dyeing	Batch
Savcan Tekstil (Netçevre Mühendislik, 2017)	Jet Dyeing	Batch
Net Tekstil (Gazi Çevre Mühendislik, 2015)	Dyeing Boiler	Batch
Gülcemal Tekstil (EKOÇED Mühendislik, 2014)	Jet Dyeing	Batch

Table 4.1 (cont'd)

Textile Plant	Reactive Dyeing Method	Process Type
Yedikardeş Tekstil (Lansy Mühendislik, 2014)	Jet Dyeing	Batch
Broş Tekstil (Mavi Yeşil Mühendislik, 2016)	HT Dyeing	Batch

4.2.3 Literature Data

The data required for the inventory analysis performed in the LCA study also includes the reactive dyeing LCA studies present in the literature. Emissions to the air, water, and soil are all considered outputs in the LCA study. In addition to the use of raw materials and energy, the emissions to air and water were also considered. The relevant data were collected from the textile plants within the scope of the BESTÜ Project and the studies in the literature. Details of the studies and the data retrieved from the literature are given in APPENDIX A.

4.2.4 Reactive Dye Material Inventory

One of the most critical points in the LCI study was the absence of reactive dyes in SimaPro databases. In order to introduce reactive dyes into SimaPro, a "reactive dye" material had to be created by manually entering the chemical dye components. For this purpose, a comprehensive literature search was conducted. Although it was challenging to reach the recipes of these patented reactive dyes, the recipe for the "Reactive Orange 12 (RO-12)" dye was obtained through the Environmental Impact Assessment Reports of the two dye production factories (Bhagwati Enviro Care, 2006; Kadam, 2021). The inventory information for Reactive Orange 12 is given in Table 4.2.

Table 4.2. Inventory for Reactive Orange 12 (per production of 1 kg RO-12)

Inputs		
Material		MT/MT
K. Acid	Beta-Naphthol	0.57
	Sulfuric Acid (98%)	1.05
	Oleum (65%)	1.15
	Water	0.57
	Sodium Sulphate (98%)	1.15
	Ammonia (24%)	0.65
	Sodium Bicarbonate (SBC)	1.22
MUA (Meta Ureido Aniline)	Water	2.08
	HCl	0.10
	MPD (meta-phenylene diamine)	0.04
	HCl	0.08
	Sodium Nitrite	0.08
	Cynauric Chloride	0.17
	Sodium Bicarbonate (SBC)	0.32
	Liquid Ammonia	0.16
Outputs		
	Sodium Bisulphate (SBS)	0.97
	CO ₂	0.04
	Spent Sulfuric Acid (40-45%)	0.97
	NH ₄ OH	0.62

Since the chemicals K. Acid and MUA in the reactive dye content are not defined in the SimaPro database, the production data of these substances were taken from the literature, and the materials forming these chemicals were entered into SimaPro. Mass balance information for the production of K. Acid (Table A. 6) and MUA (Table A. 7) is given in APPENDIX A.

4.2.5 Atmospheric Emissions

The data for the atmospheric emissions released from the reactive dyeing process were adopted from the studies in the literature and the BESTÜ Project data. However, in order to show the variations in these emissions due to different dyeing methods, it was necessary to identify the main source of the emissions. Since the main factor that can cause atmospheric emissions in the dyeing stages is the production and use of steam, the variations in the emission data are associated with the amount of steam used. Therefore, the CO, SO₂, NO_x, dust, and VOC emission levels in the collected raw inventory data were recalculated per kg steam usage. As a result of this study, it was seen that the emission distributions in the literature and real plant data were very close to each other. The final inventory of the emissions released per kg of steam usage was created by taking an average of the given data. As a result, the specific emission data in Table 4.3 were used as a multiplier for varying air emission values depending on the use of different steam amounts in different dyeing methods.

Table 4.3. Specific Air Emission per kg Steam Used in Dyeing

Parameter	Unit	Data
Specific CO emission	g/kg steam used	0.20
Specific SO ₂ emission	g/kg steam used	0.22
Specific NO _x emission	g/kg steam used	0.28
Specific dust emission	g/kg steam used	0.06
Specific VOC emission	g/kg steam used	0.10

4.3 Scenario Development

LCA scenarios were created by taking into consideration both different reactive dyeing methods and different membrane filtration applications.

The selected dyeing method greatly affects water and energy consumption in reactive dyeing. In the textile industry, reactive dyes are applied to textile materials in rope

and open-width forms. In general, for dyeing, textile materials in rope form jet dyeing are widely used, which is a batch process. For reactive dyeing of open-width pieces, while jiggers are commonly employed for batch dyeing, the pad-steam method is used for continuous dyeing.

As suggested by the Textile Industry BREF document and the studies in the literature, direct UF, direct NF, and UF+NF combination membrane applications give satisfactory results for the salt/dye fractionation and reuse of reactive dyeing wastewater. Therefore, these three applications were taken into consideration while developing the membrane filtration scenarios. For the design of membrane scenarios, WAVE software was used in this study.

The combinations of reactive dyeing methods and membrane filtration applications for the salt/dye fractionation and reuse of wastewater created the studied scenarios and were evaluated through the LCA study. A total of 12 scenarios were created and Table 4.4 is prepared to represent the scenarios better.

Table 4.4. Studied Scenarios

Studied Scenario	Reactive Dyeing Method	Treatment Method
Scenario 1.a – Jet Baseline	Jet Dyeing	Direct Discharge
Scenario 1.1	Jet Dyeing	Direct UF
Scenario 1.2	Jet Dyeing	Direct NF
Scenario 1.3	Jet Dyeing	UF+NF
Scenario 2.a – Jigger Baseline	Jigger Dyeing	Direct Discharge
Scenario 2.1	Jigger Dyeing	Direct UF
Scenario 2.2	Jigger Dyeing	Direct NF
Scenario 2.3	Jigger Dyeing	UF+NF
Scenario 3.a – Pad Baseline	Pad-Steam Dyeing	Direct Discharge
Scenario 3.1	Pad-Steam Dyeing	Direct UF
Scenario 3.2	Pad-Steam Dyeing	Direct NF
Scenario 3.3	Pad-Steam Dyeing	UF+NF

4.4 Membrane Process Design with WAVE Water Treatment Design

DuPont's "Water Application Value Engine" (WAVE) is a robust integrated software that can be used to develop and model water and wastewater treatment systems of UF, RO, ion exchange (IX), and Closed-Circuit Reverse Osmosis (CCRO) (LaRue et al., 2022).

The use of WAVE provides the efficiency and performance estimation for any UF, RO, and NF process combination application for the water or wastewater containing aqueous salts or organics. The program integrates theoretical models, such as Darcy's Law, with actual full-scale operational data that the manufacturer gathers and validates. When calculated parameters (for example, flow rates) are found to be outside of the approved design specifications, WAVE will give design warnings. The presence of these warnings indicates that the treatment system is not functioning as it should be. If the design parameters are not adjusted to address the issues raised by the warnings, then the design cannot be considered complete.

WAVE can anticipate system behavior under several variables, such as different solution chemical compositions, temperatures, pressures, and the selection, configuration, or arrangement of unit processes (LaRue et al., 2022). Due to these features, WAVE is highly preferred for the simulations of full-scale designs, and its performance has been found to be successful in practice. WAVE's usage in full-scale design simulations was demonstrated in Chino, California, where it was successfully employed to develop a membrane system. With the initiation of the Chino Basin Desalter Authority, WAVE was used to model several different membrane systems that can handle the high nitrate concentration problem in the groundwater. As a result, the one with the optimal combination of nitrate removal and energy consumption was chosen, and the high nitrate problem was successfully solved (Dupont Water Solutions, 2020). Considering the WAVE's success in full-scale membrane system simulations, membrane filtration designs under this study's scope were created using WAVE software. The results obtained from the WAVE software forms the inventory data of the membrane scenarios.

Regardless of the dyeing method chosen, the highest concentrations of dyes and auxiliaries were observed in the dyeing bath, followed by hot rinsing and soap washing steps. The last step, warm rinsing, has a remarkably low concentration of pollutants. Therefore, wastewater treatment from the first three stages is the key to reusing water in dyeing. In this regard, the composition and flow rates of the wastewater from the first three stages were incorporated into the membrane treatment scenarios, and designs were created based on these data.

In order to determine the flow rates and compositions of feed water to membranes, the effluent from three different reactive dyeing methods was analyzed. For this purpose, a comprehensive inventory analysis was conducted, for which the details are given in [Section 5.1](#).

For the direct UF application design, among the UF modules offered in WAVE, IntegraPac IP-51XP with 0.03-micron pore size was selected, as the optimum operation performance was obtained with this module for all direct UF scenarios. The typical properties and suggested operating conditions of the module are given in Table 4.5.

Table 4.5. Typical Properties and Suggested Operation Conditions of IP-51XP Module (Dupont Water Solutions, 2019b)

Parameter	SI units	US units
Membrane Area	51 m ²	549 ft ²
Length	1,991 m	78.4 in
Diameter	0.225 m	8.9 in
Weight (empty)	53 kg	117 lb
Weight (water filled)	102 kg	225 lb
Water Volume	49 L	12.9 gal
Filtrate Flux (25 °C)	40 – 90 l/m ² /hr	24 – 53 gfd
Flow Range per Module	2.0 – 6.9 m ³ /hr	8.8 – 30.4 gpm
Temperature	1 – 40 °C	34 – 104 °F
Maximum Inlet Module Pressure (20°C)	6.25 bar	90.65 psi
Maximum Inlet Module Pressure (40°C)	4.75 bar	68.89 psi

Table 4.5 (cont'd)

Parameter	SI units	US units
Maximum Operating TMP	2.1 bar	30.5 psi
Maximum Operating Air Scour Flow	12 Nm ³ /hr	7.1 scfm
Maximum Backwash Pressure	2.5 bar	
Operating pH	2 – 11	
Maximum NaOCl	2,000 mg/L	
Maximum Particle Size	300 µm	
Expected Filtrate Turbidity	≤ 0.1 NTU	
Expected Filtrate SDI	≤ 2.5	

For the system designs of direct NF and UF+NF applications, the same NF module was used, which is NF270-400/34i. The selection of the NF module was of critical importance since low salt rejection should be achieved to reuse the brackish permeate in reactive dyeing. Among the NF modules listed in WAVE, NF270-400/34i provided the lowest salt rejection. The typical properties and suggested operating conditions of the NF270-400/34i module are tabulated and given in Table 4.6.

Table 4.6. Typical Properties and Suggested Operation Conditions of NF270-400/34i Module (Dupont Water Solutions, 2021)

Parameter	SI units	US units
Active area	37 m ²	400 ft ²
Permeate flow rate	47 m ³ /d	12,500 GPD
Maximum Operating Temperature	45 °C	113 °F
Maximum Operating Pressure	41 bar	600 psig
Maximum Element Pressure Drop	1 bar	15 psig
Maximum Feed Silt Density Index (SDI)		SDI 5
pH Range		
Continuous operation		3 - 10
Short-Term Cleaning (30 min.)		1 - 12

The selected UF module for UF+NF combination design is IntegraFlux SFP-2860XP. In this scenario, the UF membrane was used as a pretreatment stage before the NF application. Therefore, a module with higher permeability was chosen for this scenario. The typical properties and suggested operating conditions of the module are tabulated and given in Table 4.7.

Table 4.7. Typical Properties and Suggested Operation Conditions of IntegraFlux SFP-2860XP Module (Dupont Water Solutions, 2019a)

Parameter	SI units	US units
Membrane Area	51 m ²	549 ft ²
Length	1,860 m	73.2 in
Diameter	0.225 m	8.9 in
Weight (empty)	48 kg	106 lb
Weight (water filled)	83 kg	183 lb
Water Volume	35 L	9.2 gal
Filtrate Flux (25 °C)	40 – 110 l/m ² /hr	24 – 65 gfd
Flow Range per Module	2.0 – 8.5 m ³ /hr	8.8 – 37.4 gpm
Temperature	1 – 40 °C	34 – 104 °F
Maximum Inlet Module Pressure (20°C)	6.25 bar	90.65 psi
Maximum Inlet Module Pressure (40°C)	4.75 bar	68.89 psi
Maximum Operating TMP	2.1 bar	30.5 psi
Maximum Operating Air Scour Flow	12 Nm ³ /hr	7.1 scfm
Maximum Backwash Pressure	2.5 bar	
Operating pH	2 – 11	
Maximum NaOCl	2,000 mg/L	
Maximum Particle Size	300 µm	
Expected Filtrate Turbidity	≤ 0.1 NTU	
Expected Filtrate SDI	≤ 2.5	

Different cleaning modes are defined in WAVE in order to prevent performance decreases caused by fouling. Backwashing is a physical cleaning mode, and in this process, the UF permeate is typically pumped in the reverse direction across the

membrane to remove foulants on the membrane surface. Chemically Enhanced Backwash (CEB) is basically the backwashing process with the addition of chemicals. The Clean-in-Place (CIP) is the most in-depth cleaning procedure, and it is carried out when the train is not in operation. The process begins with backwashing and continues with a chemical cleaning solution which is recycled and recirculated within the system. In the final step, the modules are submerged in the solution with no circulation taking place before the final backwash is carried out. In this process, heating the chemicals may result in an enhancement in the CIP's overall efficiency. Different durations and cleaning frequencies are defined in WAVE for these three cleaning modes. Although these predefined durations can be changed manually, the default values were used in the membrane designs.

In WAVE membrane treatment simulations, the removal of some wastewater constituents cannot be monitored, as these parameters cannot be introduced to the “feed water” tab of the WAVE software. Therefore, a literature study was required to calculate the removal of these pollutant parameters. For each parameter, an average of the literature values of the removals in UF and NF membrane treatments was taken, considering the conditions in the studies, and the results are presented in Table 4.8.

Table 4.8. Membrane Removals of Specific Pollutants

Pollutants	UF Removal (%)	NF Removal (%)	References
Phosphorus	25	85	(Hurtado & Cancino-Madariaga, 2014; Leo et al., 2011; Nir et al., 2009; Zeng et al., 2018)
Ammonia	30	85	
Chromium (Cr)	10	90	(Al-Rashdi et al., 2013; Bernat et al., 2007; Pandya Er, 2015; Tintaya et al., 2020; Verma et al., 2021)
Copper (Cu)	10	99	
Nickel (Ni)	10	90	
Cadmium (Cd)	10	95	

Table 4.8 (cont'd)

Pollutants	UF Removal (%)	NF Removal (%)	References
COD	70	80	(Simonič, 2009; Sudheer Kumar et al., 2009)
Di-(2-ethylhexyl) phthalate (DEHP)	85	99	(Kiso et al., 2001)
Adsorbable Organic Halogens (AOX) species			
Trichlorobenzenes (TCB)	60	85	(Sudheer Kumar et al., 2009)
1,2,3,5 Tetrachlorobenzenes (TECB)	60	85	
Pentachlorobenzenes (PCB)	60	85	
Hexachlorobenzenes (HCB)	60	85	

In membrane treatment scenarios, it is also not possible to observe the color removal efficiency from the results of the WAVE system design. Depending on the results of existing literature studies, reusing the brackish permeate from direct UF, direct NF, and UF+NF combined systems back again in reactive dyeing is deemed to be possible. The extent of reuse is restricted by the shade intensity of the dye to be applied to the textile material. Within the scope of this study, the suitability of the permeate obtained from the membrane systems for reuse in terms of color intensity was not evaluated. It was assumed that the obtained brackish permeate would be used in the dyeing processes to be made in shades suitable for reuse.

4.5 Life Cycle Assessment Study

4.5.1 Goal and Scope Definition

This LCA study aims to evaluate the reuse of wastewater from reactive dyeing processes, after treatment with three different membrane applications, with regards

to their impacts on the environment and to compare the results of each of these membrane treatment scenarios with each other.

The system boundary was defined as “cradle-to-grave”. Within this cradle-to-grave boundary, raw material acquisition, dyeing processes, and wastewater treatment stages were taken into account. A general representation of the system boundaries is presented in Figure 4.1.

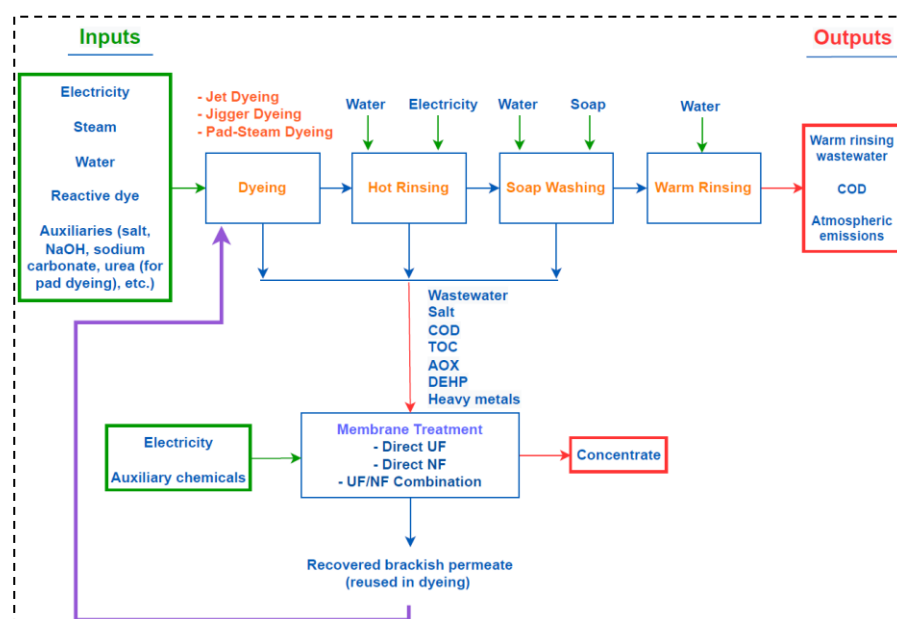


Figure 4.1. System Boundary for Membrane Treatment Scenarios

For the reactive dyeing process, steam, electricity, water, dye, and auxiliary chemicals such as salt, NaOH, sodium carbonate (soda), urea, etc., were listed as input materials. It should be noted that steam to be used in the dyeing process is produced on-site at the textile mills. Therefore, the production process of the steam produced by the steam boilers is also included in the system boundaries. The details of the steam production is given in Table A. 5 in APPENDIX A.

The stages of washing and rinsing come after the dyeing stage. During these stages, water, electricity, and soap are all considered to be inputs. At the end of the dyeing and washing processes, while the wastewater from the last warm rinsing stage is

discharged, the wastewater from the first three steps with high concentrations of pollutants such as COD, Adsorbable Organic Halogens (AOX), heavy metals, and salt enters the membrane treatment process. While electricity and auxiliary chemicals are the inputs to the treatment process with the membrane, there is a concentrate output. The recovered decolorized brackish permeate from this stage is given at the beginning of the dyeing process. In the LCA study, calculations were made by creating a mass balance for water and salt, considering the reused brine while calculating the input amounts to the dyeing process.

In Figure 4.2, the system boundary of the baseline scenario is presented. In contrast to the membrane treatment scenarios, all dyeing, washing, and rinsing wastewater is directly discharged in this scenario. Within the scope of the LCA studies, direct discharge scenarios and brackish water recovery after membrane treatment scenarios were compared to each other.

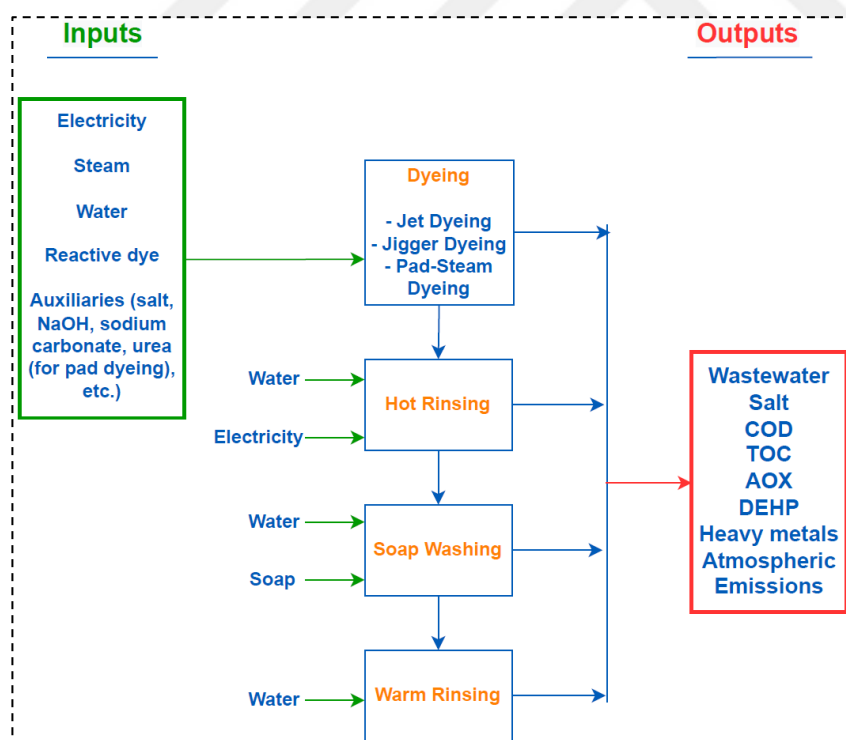
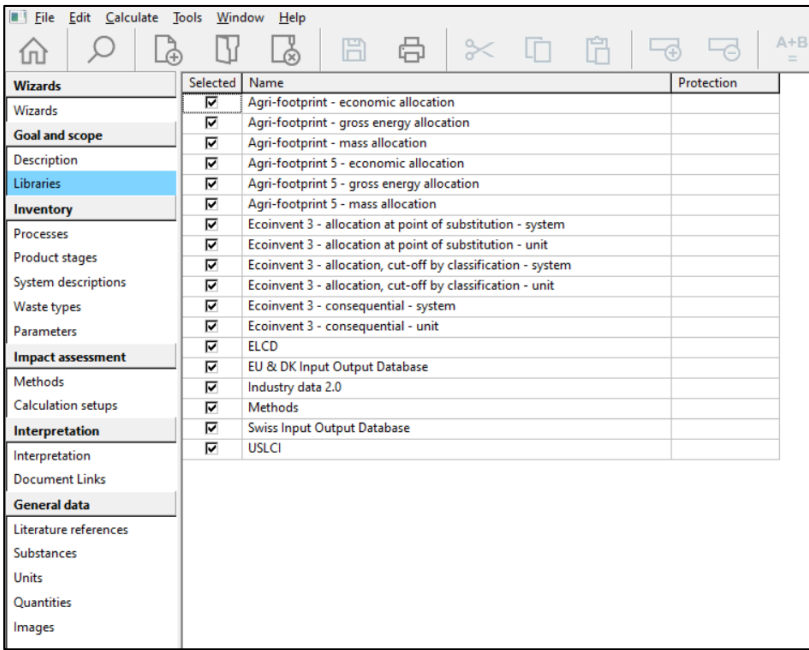


Figure 4.2. System Boundary for Direct Discharge Baseline Scenario

For all scenarios, data on the acquisition of raw materials, energy, and auxiliary chemicals were obtained from the SimaPro inventory databases and included in the scope of the LCA study. SimaPro contains several databases in its library, the list of which can be seen in Figure 4.3.



Selected	Name	Protection
☒	Agri-footprint - economic allocation	
☒	Agri-footprint - gross energy allocation	
☒	Agri-footprint - mass allocation	
☒	Agri-footprint 5 - economic allocation	
☒	Agri-footprint 5 - gross energy allocation	
☒	Agri-footprint 5 - mass allocation	
☒	Ecoinvent 3 - allocation at point of substitution - system	
☒	Ecoinvent 3 - allocation at point of substitution - unit	
☒	Ecoinvent 3 - allocation, cut-off by classification - system	
☒	Ecoinvent 3 - allocation, cut-off by classification - unit	
☒	Ecoinvent 3 - consequential - system	
☒	Ecoinvent 3 - consequential - unit	
☒	ELCD	
☒	EU & DK Input Output Database	
☒	Industry data 2.0	
☒	Methods	
☒	Swiss Input Output Database	
☒	USLCI	

Figure 4.3. Databases Present in SimaPro Library

During the LCA study, the library's whole collection of databases was utilized. In Ecoinvent database, all the activities are defined based on the geographic locations so that the processes and technologies present in the location can be reflected in the LCA study. The LCA studies within the scope of this thesis were not aimed to be conducted for a specific location and are intended to reflect global data. For this reason, global datasets were selected in the Ecoinvent database when it is available. The definitions and location information of the data selected from the databases are indicated in the inventory tables given under [Section 5.1](#). Although the Ecoinvent is primarily preferred, other databases were also used to supplement in case of the absence of information in Ecoinvent. On the other hand, the material had to be

defined manually and introduced to the system for reactive dye material input since it was not present in any of the databases of the SimaPro library.

After the definition and goal, and scope of the study, the functional unit was defined to establish a relationship between inputs and outputs. To ensure that LCA results are comparable, this relationship is essential. In the case of reactive textile dyeing, the functional unit was defined as "1 ton of fabric dyed". The reason for determining the functional unit as 1 ton of dyed fabric is to calculate the environmental impacts of the variation in the amount of wastewater generated by different dyeing processes. Hence, the functional unit was not determined based on the amount of wastewater but rather on the amount of dyed fabric.

In the textile sector, the recipes of salt, dye, and other auxiliary chemicals are given per 1 kg of textile material to be dyed and the recipes do not change with the change of dyeing method. As it is assumed that the same amount of textile material, 1 ton of fabric, is dyed in all dyeing scenarios, the amounts of auxiliary chemicals used do not change between the scenarios. However, water consumption changes between different dyeing methods, resulting in the differing wastewater composition for each dyeing method. In addition, steam and electricity consumption levels are different for each dyeing method as well as emission levels, which are associated mainly with steam consumption. During the course of the LCA studies, a number of assumptions were made, and a list of these assumptions is provided in APPENDIX B.

4.5.2 Life Cycle Inventory Analysis

Through the life cycle inventory analysis, inputs, which included the consumption of raw materials and energy for each functional unit, as well as the system outputs, such as wastewater and other emission streams, in reactive dyeing and the subsequent treatment stages, were defined and quantified. The degree of precision and the extent of the gathered data significantly affect the rest of the LCA study and the results. Therefore, particular importance has been attached to the accuracy of the

inventory data used in this study. The raw data required for inventory analysis were collected from the Turkish textile mills within the scope of the BESTÜ Project, Turkish textile companies with EIA files open to public access, and reactive dyeing LCA studies available in the literature. For the inventory data of membrane treatment scenarios, the outputs of WAVE software were used. After analyzing all these data, the final inventory data set was created by taking the raw data's mean or median values so that the final data set would be compatible with the scope of this study. The use of data from real textile mills and the WAVE software, which provides full-scale operation data for membrane treatment, ensured a high level of inventory data quality in the LCA study.

In order to compare the developed scenarios, reactive dyeing and membrane treatment steps were first defined as a "process". Afterward, in order to define to the system that the reactive dyeing and membrane treatment processes are consecutive stages, these two processes were selected in the "product stages" tab, and an "assembly" was created. Each developed reactive dyeing scenario was defined by SimaPro as an "assembly". After the life cycles for the scenarios were established, the scenarios were compared with the selected impact assessment method.

4.5.3 Life Cycle Impact Assessment

The results of the life cycle impact assessment can be computed with the help of the many methods that are included in SimaPro. The structure of impact assessment methods consists of four main parts, the explanations of which are given below.

1. Characterization:

A characterization factor (CF) multiplier expresses each substance's proportionate contribution to the impact category when applied to the related substances. After multiplying all materials contributing to an impact category by their CF, the values are summed, and this total indicates the impact category indicator at the "mid-point" level.

2. Damage Assessment:

The purpose of damage assessment is the combination of impact category indicators at the mid-point level that contribute to the same end-point impact category into one damage category (end-point category).

3. Normalization:

A baseline is established by normalization to facilitate comparisons between different environmental impact categories with the same unit, which is accomplished by dividing the impact categories by the reference values. The output of the normalization step serves as an input for the subsequent weighting step.

4. Weighting:

The relative importance of various impact categories can be identified through the weighting stage of a life cycle impact assessment study. In this stage, a weighting factor is assigned to each impact category. In the normalization and weighting steps, the different environmental impact categories are compared, and a single impact score is generated by weighting factors assigned to each impact category based on their relative importance.

Impact assessment can be conducted using both end-point and mid-point indicators. Since the assumptions are minimized and the indicators are less ambiguous, the mid-point method has a stronger connection to environmental flows. In the end-point characterization, it is easier to comprehend and interpret indicators owing to the clear connections to environmental flows. These two different characterization methods are actually complementary to each other, and both characterization methods should be discussed when interpreting the LCA results.

In order to conduct a study that is compatible with ISO standards, one of the most crucial steps is to choose the most suitable method for the impact assessment and to identify the impact categories relevant to the purpose and scope of the study. In order to meet the ISO 14044 standard requirements, an LCA study is obliged to consider all relevant impact categories for the study. Therefore, ISO 14044 standard does not

allow the use of single-issue methods. The single-issue methods are developed to assess the environmental impacts in terms of only one impact category, such as carbon footprint or water footprint. Accordingly, within the scope of this study, single-issue methods were not included in the evaluation during the impact assessment method selection process.

In selecting the impact assessment method to be used in this LCA study, primarily, reactive dyeing LCA studies available in the literature were scanned. In addition, the impact calculation structures of the methods available in SimaPro and the associated impact categories were investigated. The methods available in SimaPro v.9.2 and their specifications are given in Table 4.9. It should be noted that the single-issue methods available in SimaPro v.9.2 are not included in the list given in Table 4.9.

Table 4.9. Impact Assessment Methods and Specifications

Methods	Characterization	Normalization	Weighting	Single Score	Damage Assessment	Characterization Factor Scale
CML-IA	✓	✓	✗	✗	✗	European
Environmental Prices	✓	✗	✓	✓	✗	European
Ecological scarcity 2013	✓	✗	✓	✓	✗	European
EF and EF 3.0 methods	✓	✓	✓	✓	✗	European
EN 15804 + A2 method	✓	✓	✓	✓	✗	European
EPD (2018)	✓	✗	✗	✗	✗	European
EPS 2015d and EPS 2015dx	✓	✗	✓	✗	✓	European
IMPACT World+ End-point	✓	✓	✓	✓	✓	Global
IMPACT World+ Mid-point	✓	✗	✗	✗	✗	Global
ReCiPe 2016 End-point (E-H-I)	✓	✓	✓	✓	✓	Global

Table 4.9 (cont'd)

Methods	Characterization	Normalization	Weighting	Single Score	Damage Assessment	Characterization Factor Scale
ReCiPe 2016 Mid-point (E-H-I)	✓	✓	✗	✗	✗	Global
BEES+	✓	✓	✓	✓	✗	North American
TRACI 2.1	✓	✓	✗	✗	✗	North American

Some of the impact assessment methods available in SimaPro include normalization, weighting, single-score, and damage assessment steps. These steps allow users to generate more comparable results and make the interpretation easier with the aid of simpler data. Therefore, methods including these steps were examined first, and the total number of methods complying with these criteria was narrowed down to two: IMPACT World+ End-point and ReCiPe 2016 End-point methods. As can be seen in Table 4.10, both methods cover the impact categories related to damage to the receiving water environment, which are important impact categories for textile dyeing due to its highly polluted wastewater. It is also possible to see that ReCiPe 2016 method covers impact categories related to resource scarcity. Because reactive dyeing is a process that requires a significant amount of raw materials, these impact categories hold a significant position in this LCA study, and it is crucial that they be taken into consideration. Additionally, although it is stated that in the IMPACT World+ End-point method, impact categories of the damage level are grouped into three indicators as human health, ecosystem quality, and resources & ecosystem services, it is not possible to generate results in “resources & ecosystem services” impact category in SimaPro v.9.2 (Bulle et al., 2019). Due to this issue stemming from the software version, the ReCiPe 2016 method provided three different damage level results, whereas the IMPACT World+ method only gave two different damage level results. When the IMPACT World+ and ReCiPe 2016 impact assessment

methods are compared, it is seen that the ReCiPe 2016 is preferable for the scope of this LCA study.

Table 4.10. Mid-point Impact Categories of ReCiPe 2016 and IMPACT World+ Methods

ReCiPe 2016 End-point (H)	IMPACT World+ End-point
Global warming, Human health	Climate change, human health, long term Climate change, human health, short term
Global warming, Terrestrial ecosystems Global warming, Freshwater ecosystems	Climate change, ecosystem quality, long Climate change, ecosystem quality, short
Stratospheric ozone depletion	Ozone layer depletion
Ionizing radiation	Ionizing radiation, human health Ionizing radiation, ecosystem quality
Ozone formation, Human health Ozone formation, Terrestrial ecosystems	Photochemical oxidant formation
Fine particulate matter formation	Particulate matter formation
Terrestrial acidification	Terrestrial acidification
Freshwater eutrophication	Freshwater eutrophication
Marine eutrophication	Marine eutrophication
-	Freshwater acidification
-	Marine acidification, long term Marine acidification, short term
Freshwater ecotoxicity	Freshwater ecotoxicity, long term Freshwater ecotoxicity, short term
Terrestrial ecotoxicity	-
Marine ecotoxicity	-
Human carcinogenic toxicity Human non-carcinogenic toxicity	Human toxicity cancer, long term Human toxicity cancer, short term Human toxicity non-cancer, long term Human toxicity non-cancer, short term
Land use	Land occupation, biodiversity Land transformation, biodiversity
Mineral resource scarcity	-

Table 4.10 (cont'd)

ReCiPe 2016 End-point (H)	IMPACT World+ End-point
Fossil resource scarcity	-
Water consumption, Human health	Water availability, terrestrial ecosystems
Water consumption, Terrestrial ecosystem	Water availability, freshwater ecosystems
Water consumption, Aquatic ecosystems	Water availability, human health
-	Thermally polluted water

In determining the impact assessment method to use, studies in the literature, which include the dyeing process in their scopes, were also reviewed. As can be seen in Table 4.11, the most preferred impact assessment methods were found to be the CML and ReCiPe methods.

Table 4.11. Impact Assessment Methods Used in the Literature

Study	Reference	Impact Assessment Method
Life Cycle Assessment of Melange Yarns from the Manufacturer Perspective	(Liu et al., 2020)	ReCiPe (GaBi)
Improved design for textile production process based on life cycle assessment	(Zhang et al., 2018)	CML2001 & USEtox (GaBi)
“LCA of textile dyeing with Acacia Dealbata tree bark: A case study research”	(Linhares & de Amorim, 2017)	ReCiPe 1:08 (H)
“Life-cycle assessment of continuous pad-dyeing technology for cotton fabrics”	(Z. W. Yuan et al., 2013)	CML2001 (GaBi)
“Life cycle assessment of cotton T-shirts in China”	(Zhang et al., 2015)	CML2001 (GaBi)
“Life Cycle Assessment for the Dyeing and Finishing Process of Organic Cotton Knitted Fabrics”	(Muruges & Selvadass, 2013)	Impact 2000+
“LCA Update of Cotton Fiber and Fabric Life Cycle Inventory”	(Jewell, 2017)	CML2001 & USEtox (GaBi)

Table 4.11 (cont'd)

Study	Reference	Impact Assessment Method
“LCA study of a new electrochemical and ultraviolet (EC-UV) combined system to decolourise and reuse textile saline effluents: Environmental evaluation and proposal to improve the production process”	(Álvarez et al., 2020)	ReCiPe (H) V1.06 mid-point and end-point
“Life cycle assessment of cotton textile products in Turkey”	(Baydar et al., 2015)	EDIP2003 (GaBi)
“Life cycle assessment of cotton woven shirts and alternative manufacturing techniques”	(Kazan et al., 2020)	CML2001 (GaBi)
“A Comparative Life Cycle Assessment of Denim Jeans and a Cotton T-Shirt: The Production of Fast Fashion Essential Items from Cradle to Gate”	(Hackett, 2015)	ReCiPe 2008
“Is Unbleached Cotton Better Than Bleached? Exploring the Limits of Life-Cycle Assessment in the Textile Sector”	(Roos et al., 2015)	ReCiPe (H) V1.06 mid-point

CML method does not have weighting, single-score, and damage evaluation steps, which is disadvantageous compared to the ReCiPe 2016 method. Additionally, with an update to the ReCiPe method in 2016, the scope of this impact assessment method has been greatly expanded. Accordingly, when more recent LCA studies were examined, a trend toward increasing the use of the ReCiPe method was observed. Therefore, the ReCiPe 2016 End-point (H) method was selected for the impact assessment. In ReCiPe 2016 impact assessment methods, three perspectives are adopted, which are Individual (I), Hierarchist (H), and Egalitarian (E). These perspectives represent different value choices, such as time horizon, age weighting, discount rate, and different uncertainties due to assumptions (de Schryver et al., 2011). The descriptions of the perspectives and the details of the impact assessment stages, together with an overview of the impact categories, are provided in APPENDIX D.

4.5.4 Interpretation

The impact assessment results were analyzed and interpreted in this last step of the LCA study. In this LCA study, three main reactive dyeing scenarios were created, each consisting of four sub-scenarios. For each main scenario, the normalized mid-point and end-point results were evaluated together with single-score results.



CHAPTER 5

RESULTS AND DISCUSSION

This chapter presents and discusses the results of the membrane treatment design simulations and the LCA study in accordance with the study's objective, which was to determine the life cycle impacts of the selected BATs for the reduction of salt usage in jet, jigger, and pad-steam reactive dyeing techniques. The BATs included in the study are based on membrane applications and are UF, NF, and UF+NF treatment systems.

Using WAVE software, three different membrane treatment simulations, UF, NF, and UF+NF, were built for each dyeing method. The results from the membrane treatment scenarios, together with the reactive dyeing process data collected from various sources, form the inventory data of this LCA study, and the results are presented in [Section 5.1](#).

Reuse scenarios were evaluated by means of the LCA study for each selected reactive dyeing technique. The results were analyzed and compared to that of direct discharge of reactive dyeing wastewater to shed light on the impacts of wastewater reuse with the use of membrane applications. The results of the life cycle impact assessment are given under [Section 5.2](#).

The impact assessment was conducted by using the ReCiPe 2016 End-point (H) method. The results of the scenarios were calculated on both mid-point and end-point basis. In both assessments, the units in the characterization results are different for each impact category. Therefore, it is not possible to compare different impact categories in different units with each other without normalization. In order to compare the scenarios with each other, the normalized results in both assessments, the results with the same units (Pt) for each impact category, were interpreted. The Recipe 2016 method can also display results in a single-score format. In the single-

score representation, the results of the normalized impact categories are summed together and displayed as a single value for each scenario. The contribution of the impact categories to the overall impact can also be seen in the single-score representation. As this is the most appropriate representation for the objective of this comparative LCA study, the results are presented and discussed in single-score format.

5.1 Membrane System Design and Inventory Data

In this section, the results of membrane treatment simulations developed using WAVE software are given together with the inventory data created for the reactive dyeing process.

There are some points that guide the reading of the inventory tables given in this section. In the tables showing the “Reactive Dyeing Inventory”, the following should be considered:

- In the reuse scenarios, the data obtained by conducting a mass balance for the water and salt inputs to the reactive dyeing process were entered into the LCA software. The table contains the data formed after the mass balance.
- For baseline scenarios, emissions to water represent the amount and content of wastewater from all dyeing stages. In reuse scenarios, emissions to water represent only the amount and content of wastewater from the 4th stage of dyeing, which is directly discharged.

In the tables showing the “Membrane Treatment Inventory”, the following should be considered:

- Inputs represent wastewater and its content from the first 3 stages of the reactive dyeing process.
- Emissions to water refer to the amount and content of the “concentrate” generated from the membrane processes.

- The amount of wastewater and salt given in the emissions to water is obtained from the membrane treatment performance results of the WAVE software.
- Other parameters in the emissions to water are the output values based on the membrane treatment performances adopted from the literature.

Further details of the membrane treatment scenarios, including the operational parameters and the permeate quality results, are given in APPENDIX C. Water and salt recovery performances of the scenarios are also presented in Table C. 34 in APPENDIX C.

5.1.1 Jet Dyeing

For rope textile pieces, the jet dyeing method, which is a batch dyeing method, was chosen as a result of the literature review on the common applications of reactive dyes. For the treatment and subsequent reuse of brackish effluent, three different membrane filtration scenarios were developed. As previously mentioned in [Section 4.3](#), a total of four scenarios were developed for jet reactive dyeing, three of which were membrane scenarios. For jet dyeing, the liquor ratio was accepted as 1:12, meaning the water consumption in each dyeing stage is 12 L per kg of fabric dyed. The total feed flow rate for all jet dyeing membrane scenarios was determined as 36 m³/h, which is the total wastewater flow rate from the dye bath, hot rinsing, and soap washing steps. In addition to flow rate, feed wastewater salt concentration was entered into the WAVE software as 11.1 g/L.

5.1.1.1 Scenario 1.a – Jet Baseline

All dyeing, washing, and rinsing wastewater is directly discharged in the baseline scenario. As there is no reuse in this scenario, there was no need for constructing a mass balance for raw material consumption. The total amount of wastewater resulting from dyeing and the subsequent hot rinsing, soap washing, and warm

rinsing stages was determined as 48 m³/ton of fabric dyed. The inventory data for Scenario 1.a is given in Table 5.1.

5.1.1.2 Scenario 1.1 (Direct UF)

The design of the UF treatment system was conducted by considering the suggested operating conditions by the manufacturer of the module, Dupont Water Solutions. These operating conditions are predefined in WAVE software, and upon the selection of the module, the engine itself restricts the values that the operational parameters can take to the ranges set by the manufacturer.

Wastewater, with a total flow rate of 36 m³ originating from dyeing, hot rinsing, and soap washing stages, where the most polluted wastewater in terms of dye and salt concentration are formed, was treated with UF. In Figure 5.1, the general representation of the designed UF treatment system is given.

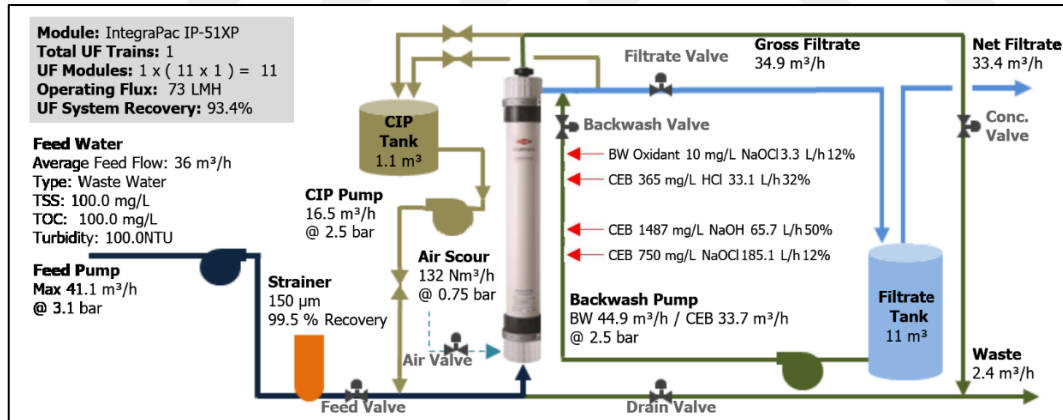


Figure 5.1. Scenario 1.1 – Direct UF System for Jet Dyeing Wastewater

The system configuration was made to have 11 UF modules in 1 train, which allowed to obtain 93.4% system recovery. Therefore, while the net filtrate (or permeate) taken from the system is calculated as 33.4 m³/h, the flow rate of the concentrated part so-called "waste" is determined as 2.4 m³/h.

The recovered decolorized brackish permeate from direct UF treatment is given at the beginning of the reactive dyeing process. Therefore, in the determination of raw material amounts to be entered to SimaPro, mass balance for water and salt was established, considering the reused brackish permeate (Figure C. 1 in APPENDIX C). The inventory data, after the reuse, for the reactive dyeing process of Scenario 1.1 is given in Table 5.1, and that of UF treatment is given in Table 5.2.

5.1.1.3 Scenario 1.2 (Direct NF)

A three-stage NF system was designed for the direct NF treatment scenario. When there are multiple stages within a train, the permeate from the first stage becomes the feed for the second stage, and so on. Using multiple stages allows higher permeate recovery and increases the concentrate water quality (LaRue et al., 2022). The multi-stage system design is the most optimum design for this study since the salt content of the water to be reused in dyeing is desired to remain in the permeate. Also, the higher the water recovery percentage, the lower the water consumption in the dyeing process, which is a desirable result in this study. Additionally, 35% of the final concentrate was recycled back to the feed of the NF system to increase the NaCl concentration in the permeate.

The system configuration was made to have 4 pressure vessels (PV) in stage 1, 3 PVs in stage 2, and 2 PVs in stage 3. 6 elements, which are NF modules, are placed in each PV, meaning the system was designed with a total of 54 elements. In Figure 5.2, the general representation of the designed NF treatment system is given.

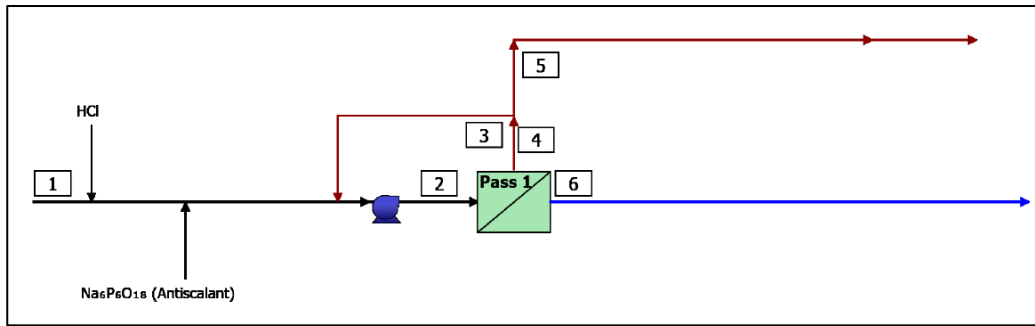


Figure 5.2. Scenario 1.2 – Direct NF System for Jet Dyeing Wastewater

This system allowed 82.2 % recovery. Therefore, while the permeate taken from the system was calculated as 29.6 m³/h, the flow rate of the concentrated part was determined as 6.41 m³/h.

The recovered decolorized brackish permeate from direct NF treatment is given at the beginning of the reactive dyeing process. Therefore, in the determination of raw material amounts to be entered to SimaPro, mass balance for water and salt was established, considering the reused brackish permeate (Figure C. 2 in APPENDIX C). The inventory data, after the reuse, for the reactive dyeing process of Scenario 1.2 is given in Table 5.1, and that of NF treatment is given in Scenario 1.3 (Combined UF+NF)

In the combined system, NF treatment follows the UF pretreatment stage. A simple flow diagram of the combined UF+NF system is presented in Figure 5.3. The overall permeate recovery rate of the system was calculated as 77.1%. The mass balance flow chart for water and salt is given in Figure C. 3 in APPENDIX C.

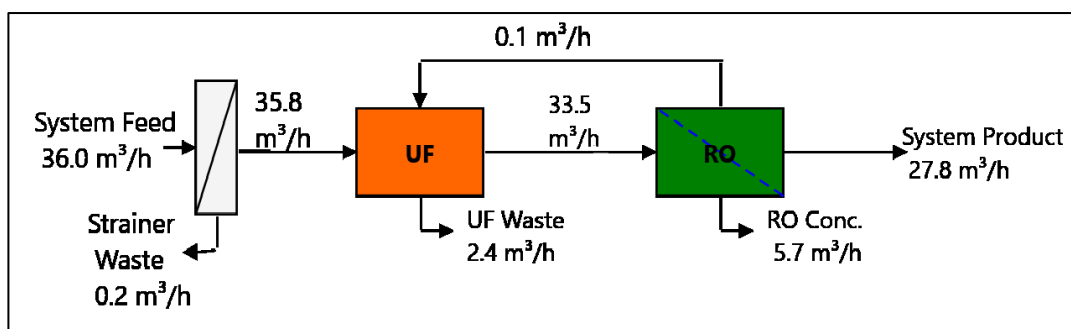


Figure 5.3. Scenario 1.3 - UF+NF Treatment System for Jet Dyeing

UF Pretreatment Design

In the combined system, NF treatment follows the UF pretreatment stage. In this scenario, for the UF pretreatment, the IntegraFlux SFP-2860XP module was chosen. This module has higher permeability than the module used in the direct UF scenario. In Figure 5.4, the general representation of the designed UF treatment system for the UF+NF combined scenario is given.

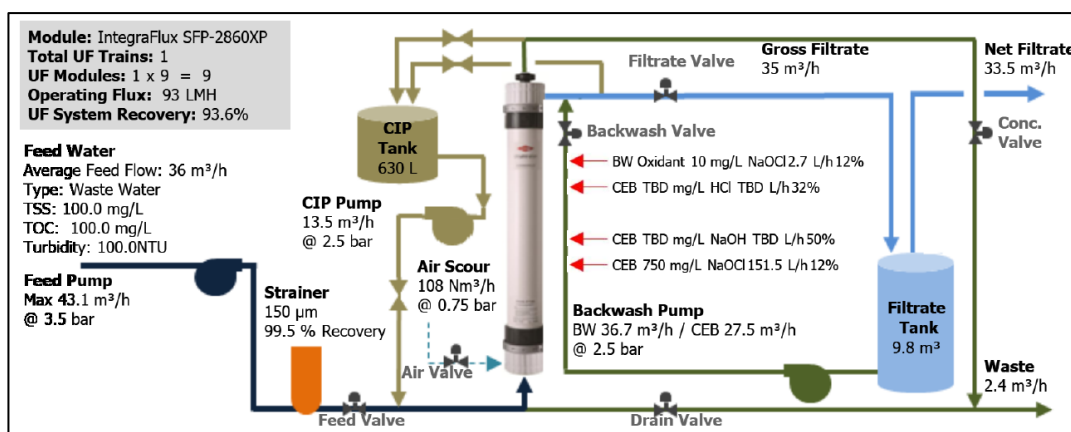


Figure 5.4. Scenario 1.3 – UF Pretreatment System for Jet Dyeing Wastewater

The system configuration was made to have 9 UF modules in 1 train, which allowed to obtain 93.6% system recovery. Therefore, while the net filtrate taken from the

system was calculated as 33.5 m³/h, the flow rate of waste was determined as 2.4 m³/h.

NF Treatment Design

A three-stage NF system with 35% concentrate recycle was designed for UF+NF treatment scenario. The system configuration was made to have 4 pressure vessels (PV) in stage 1, 3 PVs in stage 2, and 2 PVs in stage 3. 6 elements, which are NF modules, are placed in each PV, meaning the system was designed with a total of 54 elements. In Figure 5.5, the general representation of the designed NF treatment system is given.

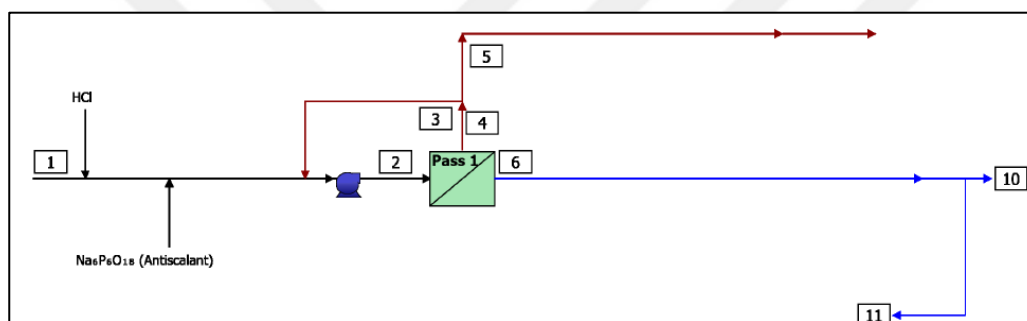


Figure 5.5. Scenario 1.3 – NF System for Jet Dyeing Wastewater

This system allowed 82.7 % recovery. Therefore, while the permeate taken from the system was calculated as 27.8 m³/h, the flow rate of the concentrate part was determined as 5.71 m³/h.

The recovered decolorized brackish permeate from UF+NF treatment is given at the beginning of the reactive dyeing process. Therefore, in the determination of raw material amounts to be entered to SimaPro, mass balance for water and salt was established, considering the reused brackish permeate. The inventory data, after the reuse, for the reactive dyeing process of Scenario 1.3 is given in Table 5.1, and that of UF pretreatment and NF treatment is given in Table 5.2.

Table 5.1. Reactive Dyeing Inventory of Jet Dyeing Scenarios (per 1 ton of fabric dyed)

Reactive Dyeing Stage						
Material	Unit	Scenario 1.a - Baseline	Scenario 1.1	Scenario 1.2	Scenario 1.3	Database Description Data Source
Softened water	kg	48000	14600	18400	20200	“Water, completely softened, (RER) /water production/Conseq, S”
Reactive dye (Reactive Orange 12)	kg	50.00	50.00	50.00	50.00	-
Salt (NaCl)	kg	400.00	29.26	128.12	150.22	“Sodium chloride, powder (GLO)/market for/Conseq, S”
Sodium carbonate	kg	20.00	20.00	20.00	20.00	“Sodium carbonate, powder (GLO)/market for/Conseq, S”
NaOH	kg	10.00	10.00	10.00	10.00	“Sodium hydroxide, without water, in 50% solution state (GLO)/market for/Conseq, S”
Surfactant	kg	19.00	19.00	19.00	19.00	“Non-ionic surfactant (GLO)/market for/Conseq, S”
Soap	kg	20.00	20.00	20.00	20.00	“Soap (GLO)/market for/Conseq, S”
Steam	kg	3600	3600	3600	3600	“Steam, in chemical industry (RER)/production/ Conseq, S”

Inputs

Table 5.1 (cont'd)

Reactive Dyeing Stage						
Material	Unit	Scenario 1.a - Baseline	Scenario 1.1	Scenario 1.2	Scenario 1.3	Database Description Data Source
Electricity	kWh	240.00	240.00	240.00	240.00	“Electricity, high voltage (GLO)/market group for/Conseq, S” - BESTÜ Project Data (Textile mills in Turkey) - EIA reports of Turkish textile mills
Wastewater	kg	48000	12000	12000	12000	-
Salt (NaCl)	kg	400.00	0	0	0	“Sodium chloride”
COD	kg	52.80	5.28	5.28	5.28	“COD (Chemical Oxygen Demand) (RER)”
TOC	kg	4.80	0.48	0.48	0.48	“TOC, Total Organic Carbon”
Phthalate, dioctyl-	mg	120.00	0	0	0	“Phthalate, dioctyl-“
Ammonia	kg	0.0410	0	0	0	-
Total P	kg	0.0450	0	0	0	-
Cr	kg	0.0081	0	0	0	-
Cu	kg	0.0154	0	0	0	-
Ni	kg	0.0151	0	0	0	-

Emissions
to Water

- Literature data

Table 5.1 (cont'd)

Reactive Dyeing Stage						
Material	Unit	Scenario 1.a - Baseline	Scenario 1.1	Scenario 1.2	Scenario 1.3	Database Description Data Source
Cd	kg	0.0067	0	0	0	-
Trichlorobenzenes (TCB)	µg	12672	0	0	0	-
1,2,3,5 Tetrachlorobenzenes (TECB)	µg	12096	0	0	0	“Benzene, 1,2,3,5-tetrachloro-“
Pentachlorobenzenes (PCB)	µg	3840	0	0	0	“Benzene, pentachloro-“
Hexachlorobenzenes (HCB)	µg	3360	0	0	0	“Benzene, hexachloro-“
CO	kg	0.73	0.73	0.73	0.73	- BESTÜ Project Data (Textile mills in Turkey)
SO ₂	kg	0.78	0.78	0.78	0.78	-
NOx	kg	1.01	1.01	1.01	1.01	- EIA reports of Turkish textile mills
Dust	kg	0.21	0.21	0.21	0.21	“Particulates, < 2.5 µm” - Literature data
VOC	kg	0.37	0.37	0.37	0.37	“VOC, volatile organic compounds as C”

Table 5.2. Membrane Treatment Inventory of Jet Dyeing Scenarios (per 1 ton of fabric dyed)

Membrane Treatment Stage						
Scenario 1.a - Baseline		Scenario 1.1	Scenario 1.2	Scenario 1.3		
Material	Unit	-	UF	NF	UF	NF
HCl	kg	N/A	0.90	0.60	0.50	0.40
“Hydrochloric acid, without water, in 30% solution state (RER)/market for/Conseq, S”						
Sodium hypochlorite (NaOCl)	kg	N/A	22.24	-	11.52	-
“Sodium hypochlorite, without water, in 15% solution state (GLO)/market for/Conseq, S”						
Citric acid	kg	N/A	0.67	-	0.41	-
“Citric acid (GLO)/ market for/Conseq, S”						
NaOH	kg	N/A	9.34	-	3.95	-
“Sodium hydroxide, without water, in 50% solution state (GLO)/market for/Conseq, S”						
Electricity	kWh	N/A	44.82	236.60	47.31	242.90
“Electricity, high voltage (GLO)/market group for/Conseq, S”						
Phosphoric acid	kg	N/A	-	0.97	-	0.90
“Phosphoric acid, industrial grade, without water, in 85% solution state (GLO)/market for/Conseq, S”						

Inputs

- WAVE Software results

Table 5.2 (cont'd)

Membrane Treatment Stage							
		Scenario 1.a - Baseline	Scenario 1.1	Scenario 1.2	Scenario 1.3		
Material	Unit	-	UF	NF	UF	NF	Data Source
NaOH (for NF)	kg	N/A	-	1.62	-	1.51	"Sodium Hydroxide, without water, in 50% solution state (GLO)/ Conseq, S"
Wastewater	kg	N/A	2400	6410	2400	5710	- WAVE Software results
Salt (NaCl)	kg	N/A	29.26	126.71	28.20	122.15	"Sodium chloride"
COD	kg	N/A	33.26	38.02	33.26	11.40	"COD (Chemical Oxygen Demand) (RER)"
TOC	kg	N/A	3.02	3.45	3.02	1.04	"TOC, Total Organic Carbon"
Phthalate, dioctyl-	mg	N/A	102	118.80	102	17.82	"Phthalate, dioctyl-"
Ammonia	kg	N/A	0.0123	0.0349	0.0123	0.0244	-
Total P	kg	N/A	0.0113	0.0383	0.0113	0.0287	-
Cr	kg	N/A	0.0008	0.0073	0.0008	0.0066	-
Cu	kg	N/A	0.0015	0.0152	0.0015	0.0137	-
Ni	kg	N/A	0.0015	0.0136	0.0015	0.0123	-
Cd	kg	N/A	0.0007	0.0064	0.0007	0.0057	-
Trichlorobenzenes (TCB)	µg	N/A	7603	10771	7603	4308	-

Emissions
to Water

- Literature data

Table 5.2 (cont'd)

Membrane Treatment Stage							
Scenario 1.a - Baseline		Scenario 1.1	Scenario 1.2	Scenario 1.3			
Material	Unit	UF	NF	UF	NF	Database Description	Data Source
1,2,3,5 Tetrachlorobenzenes (TECB)	µg	N/A	7258	10282	7258	4113	“Benzene, 1,2,3,5-tetrachloro-“
Pentachlorobenzenes (PCB)	µg	N/A	2304	3264	2304	1306	“Benzene, pentachloro-“
Hexachlorobenzenes (HCB)	µg	N/A	2016	2856	2016	1142	“Benzene, hexachloro-“

5.1.2 Jigger Dyeing

For reactive dyeing of open-width pieces, dyeing methods both in batch and continuous modes were reviewed. As a result of the literature review, the jigger dyeing method was chosen for batch dyeing. As previously mentioned in [Section 4.3](#), a total of four scenarios were developed for jigger reactive dyeing, three of which were membrane scenarios. For jigger dyeing, the liquor ratio was accepted as 1:8, meaning the water consumption in each dyeing stage is 8 L per kg of fabric dyed. The total feed flow rate for all jigger dyeing scenarios was determined as 24 m³/h, which is the total wastewater flow rate from the dye bath, hot rinsing, and soap washing steps. In addition to flow rate, feed wastewater salt concentration was entered into the WAVE software as 16.7 g/L.

5.1.2.1 Scenario 2.a – Jigger Baseline

All dyeing, washing, and rinsing wastewater is directly discharged in the baseline scenario. As there is no reuse in this scenario, there was no need for constructing a mass balance for raw material consumption. The total amount of wastewater resulting from dyeing and the subsequent hot rinsing, soap washing, and warm rinsing stages was determined as 36 m³ per 1 ton of fabric. The inventory data for Scenario 2.a is given in Table 5.3.

5.1.2.2 Scenario 2.1 (Direct UF)

The UF module used for this scenario is IP-51XP, which is the same for all direct UF scenarios. The total feed flow rate to the UF system was determined as 24 m³/h. In Figure 5.6, the general representation of the designed UF treatment system is given.

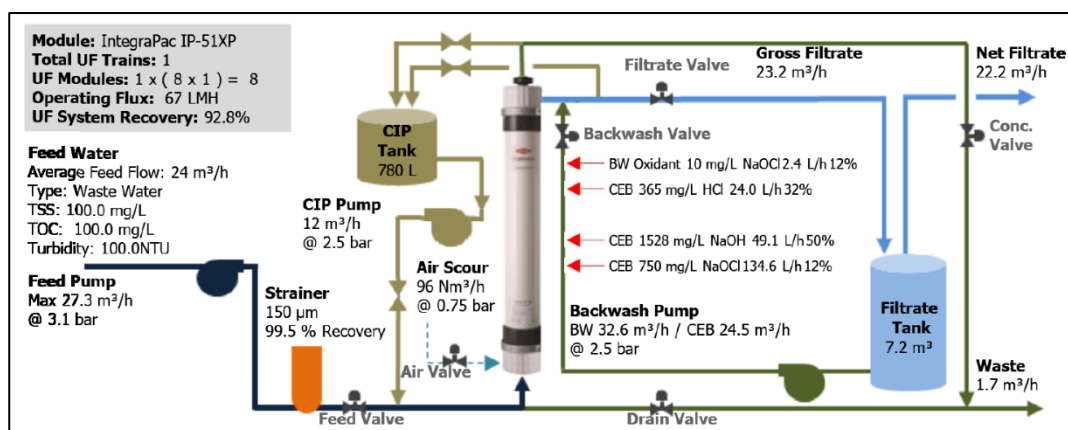


Figure 5.6. Scenario 2.1 – Direct UF System for Jigger Dyeing Wastewater

The system configuration was made to have 8 UF modules in 1 train, which allowed to obtain 92.8% system recovery. Therefore, while the permeate taken from the system was calculated as 22.2 m³/h, the flow rate of the concentrate was determined as 1.7 m³/h.

The inventory data, after the reuse, for the reactive dyeing process of Scenario 2.1 is given in Table 5.3, and that of UF treatment is given in Table 5.4. The mass balance flow chart for water and salt is given in Figure C. 4 in APPENDIX C.

5.1.2.3 Scenario 2.2 (Direct NF)

A four-stage NF system with 35% concentrate recycle was designed for UF+NF treatment scenario. The system configuration was made to have 3 pressure vessels (PV) in stage 1, 2 PVs in stage 2, 2 PVs in stage 3, and 1 PV in stage 4. 6 elements, which are NF modules, are placed in each PV, meaning, the system was designed with a total of 48 elements. In Figure 5.7, the general representation of the designed NF treatment system is given.

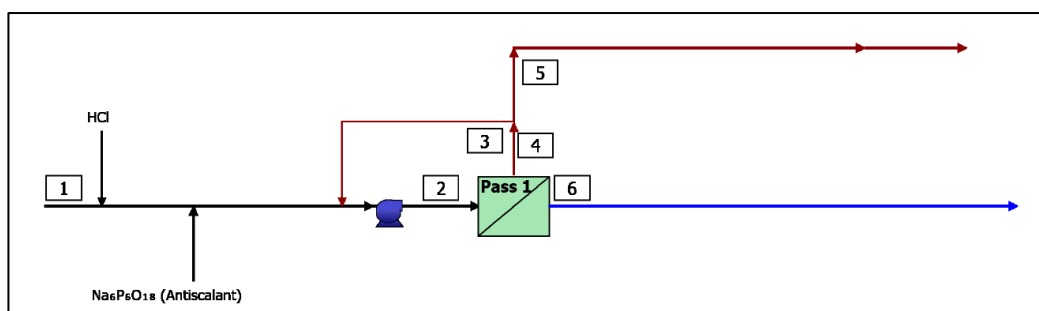


Figure 5.7. Scenario 2.2 – Direct NF System for Jigger Dyeing Wastewater

This system allowed 79 % recovery, which is comparatively lower than the recovery efficiency in the jet dyeing scenario. It was an expected result as the NaCl concentration in the jigger dyeing scenario is significantly higher due to lower wastewater volume. Therefore, while the permeate taken from the system was calculated as 19 m³/h, the flow rate of the concentrated part was determined as 5.03 m³/h. Based on these results, inventory data for Scenario 2.2 was generated. The inventory data, after the reuse, for the reactive dyeing process of Scenario 2.2 is given in Table 5.3, and that of NF treatment is given in Table 5.4. The mass balance flow chart for water and salt is given in Figure C. 5 in APPENDIX C.

5.1.2.4 Scenario 2.3 (Combined UF+NF)

A simple flow diagram generated by WAVE of the combined UF+NF system for Scenario 2.3 is presented in Figure 5.8. The overall permeate recovery rate of the system was calculated as 70.4%. The mass balance flow chart for water and salt is given in Figure C. 6 in APPENDIX C.

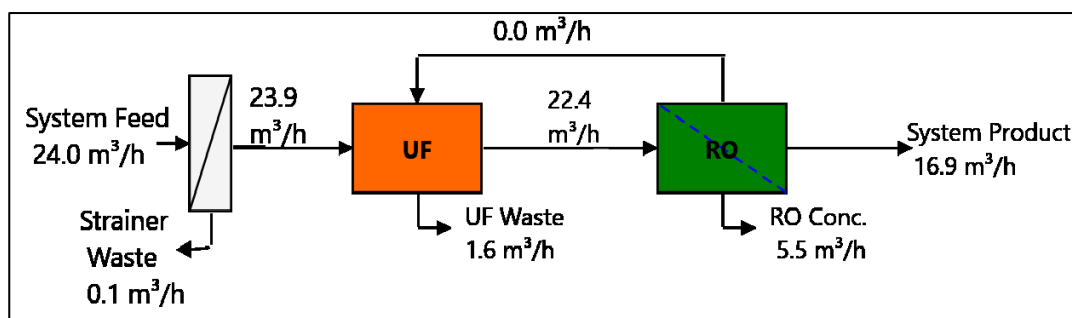


Figure 5.8. Scenario 2.3 - UF+NF Treatment System for Jigger Dyeing

UF Pretreatment Design

In this scenario, the IntegraFlux SFP-2860XP module was chosen for the UF pretreatment. In Figure 5.9, the general representation of the designed UF treatment system for the UF+NF combined scenario is given.

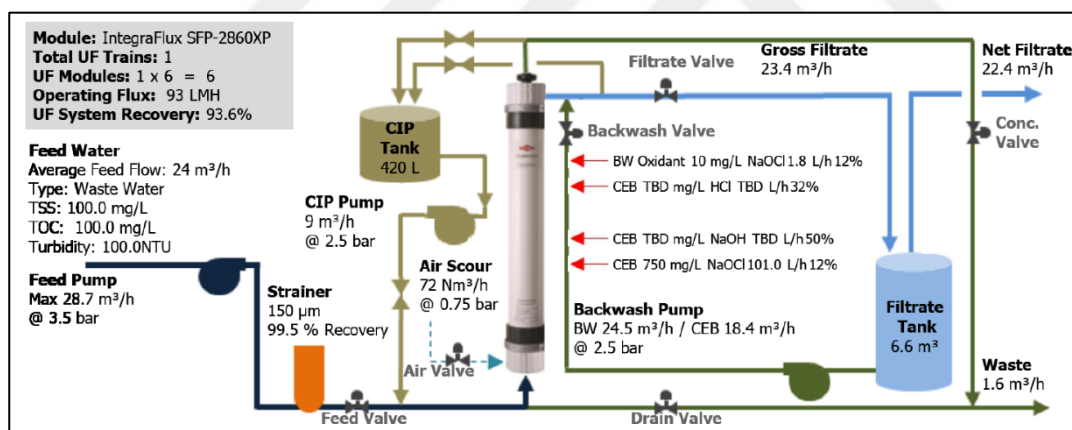


Figure 5.9. Scenario 2.3 – UF Pretreatment System for Jigger Dyeing Wastewater

The system configuration was made to have 6 UF modules in 1 train, which allowed 93.6% system recovery. Therefore, while the permeate was calculated as 22.4 m³/h, the flow rate of waste was determined as 1.6 m³/h.

NF Treatment Design

A four-stage NF system with 35% concentrate recycle was designed for UF+NF treatment scenario. The system configuration was made to have 3 pressure vessels (PV) in stage 1, 2 PVs in stage 2, 2 PVs in stage 3, and 1 PV in stage 4. 6 elements, which are NF modules, are placed in each PV, meaning, the system was designed with a total of 48 elements. In Figure 5.10, the general representation of the designed NF treatment system is given.

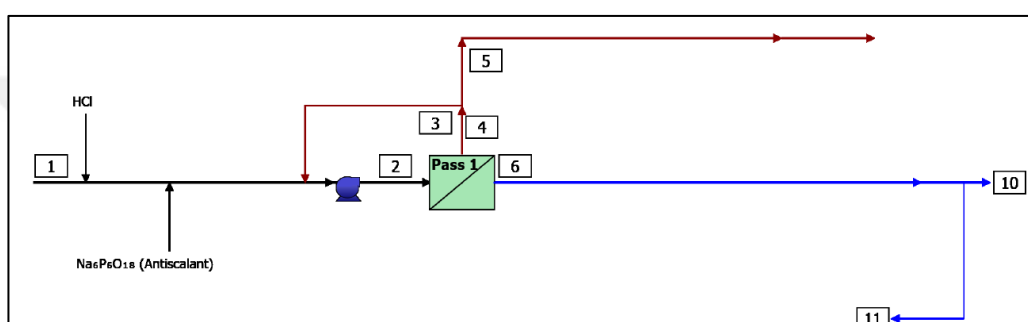


Figure 5.10. Scenario 2.3 – NF System for Jigger Dyeing Wastewater

This system allowed 75.5 % recovery. Therefore, while the permeate taken from the system was calculated as 16.9 m³/h, the flow rate of the concentrate part was determined as 5.42 m³/h.

The membrane design results from WAVE and the reactive dyeing inventory from the literature together formed the life cycle inventory of Scenario 2.3. The inventory data, after the reuse, for the reactive dyeing process of Scenario 2.3 is given in Table 5.3, and that of UF pretreatment and NF treatment is given in Table 5.4.

Table 5.3. Reactive Dyeing Inventory of Jigger Dyeing Scenarios (per 1 ton of fabric dyed)

Reactive Dyeing Stage						
Material	Unit	Scenario 2.a - Baseline	Scenario 2.1	Scenario 2.2	Scenario 2.3	Database Description Data Source
Softened water	kg	36000	9800	13000	15100	“Water, completely softened, (RER) /water production/Conseq, S”
Reactive dye (Reactive Orange 12)	kg	50.00	50.00	50.00	50.00	-
Salt (NaCl)	kg	400.00	29.28	128.43	166.76	“Sodium chloride, powder (GLO)/market for/Conseq, S”
Sodium carbonate	kg	20.00	20.00	20.00	20.00	“Sodium carbonate, powder (GLO)/market for/Conseq, S”
NaOH	kg	10.00	10.00	10.00	10.00	“Sodium hydroxide, without water, in 50% solution state (GLO)/market for/Conseq, S”
Surfactant	kg	19.00	19.00	19.00	19.00	“Non-ionic surfactant (GLO)/market for/Conseq, S”
Soap	kg	20.00	20.00	20.00	20.00	“Soap (GLO)/market for/Conseq, S”
Steam	kg	1200	1200	1200	1200	“Steam, in chemical industry (RER)/production/ Conseq, S”

Inputs

- BESTÜ Project Data
(Textile mills in Turkey)
- EIA reports of Turkish textile mills

Table 5.3 (cont'd)

Reactive Dyeing Stage						
Material	Unit	Scenario 2.a - Baseline	Scenario 2.1	Scenario 2.2	Scenario 2.3	Database Description Data Source
Electricity	kWh	140.00	140.00	140.00	140.00	“Electricity, high voltage (GLO)/market group for/Conseq, S” - BESTÜ Project Data (Textile mills in Turkey) - EIA reports of Turkish textile mills
Wastewater	kg	36000	8000	8000	8000	-
Salt (NaCl)	kg	400.00	0	0	0	“Sodium chloride”
COD	kg	35.20	3.52	3.52	3.52	“COD (Chemical Oxygen Demand) (RER)”
TOC	kg	3.20	0.32	0.32	0.32	“TOC, Total Organic Carbon”
Phthalate, dioctyl-	mg	80.00	0	0	0	“Phthalate, dioctyl-“
Ammonia	kg	0.0410	0	0	0	-
Total P	kg	0.0450	0	0	0	-
Cr	kg	0.0081	0	0	0	-
Cu	kg	0.0154	0	0	0	-
Ni	kg	0.0151	0	0	0	-

**Emissions
to Water**

- Literature data

Table 5.3 (cont'd)

Reactive Dyeing Stage						
Material	Unit	Scenario 2.a - Baseline	Scenario 2.1	Scenario 2.2	Scenario 2.3	Database Description Data Source
Cd	kg	0.0067	0	0	0	-
Trichlorobenzenes (TCB)	µg	12672	0	0	0	-
1,2,3,5 Tetrachlorobenzenes (TECB)	µg	12096	0	0	0	“Benzene, 1,2,3,5-tetrachloro-“
Pentachlorobenzenes (PCB)	µg	3840	0	0	0	“Benzene, pentachloro-“
Hexachlorobenzenes (HCB)	µg	3360	0	0	0	“Benzene, hexachloro-“
CO	kg	0.24	0.24	0.24	0.24	-
SO ₂	kg	0.26	0.26	0.26	0.26	-
NOx	kg	0.34	0.34	0.34	0.34	-
Dust	kg	0.07	0.07	0.07	0.07	“Particulates, < 2.5 µm”
VOC	kg	0.12	0.12	0.12	0.12	“VOC, volatile organic compounds as C”
Emissions to Air						- BESTÜ Project Data (Textile mills in Turkey) - EIA reports of Turkish textile mills - Literature data

Table 5.4. Membrane Treatment Inventory of Jigger Dyeing Scenarios (per 1 ton of fabric dyed)

Membrane Treatment Stage						
		Scenario 2.a - Baseline	Scenario 2.1	Scenario 2.2	Scenario 2.3	
Material	Unit	-	UF	NF	UF	NF
HCl	kg	N/A	0.70	0.40	0.30	0.30
Sodium hypochlorite (NaOCl)	kg	N/A	16.18	-	7.67	-
Citric acid	kg	N/A	0.49	-	0.28	-
Inputs	NaOH	N/A	6.98	-	2.71	-
	Electricity	N/A	30.33	175.10	32.34	166.80
	Phosphoric acid	N/A	-	0.65	-	0.60
“Hydrochloric acid, without water, in 30% solution state (RER)/market for/Conseq, S” “Sodium hypochlorite, without water, in 15% solution state (GLO)/market for/Conseq, S” “Citric acid (GLO)/ market for/Conseq, S” “Sodium hydroxide, without water, in 50% solution state (GLO)/market for/Conseq, S” “Electricity, high voltage (GLO)/market group for/Conseq, S” “Phosphoric acid, industrial grade, without water, in 85% solution state (GLO)/market for/Conseq, S”						
						- WAVE Software results

Table 5.4 (cont'd)

Membrane Treatment Stage						
Scenario 2.a - Baseline		Scenario 2.1	Scenario 2.2	Scenario 2.3		
Material	Unit	UF	NF	UF	NF	Data Source
NaOH (for NF)	kg	N/A	-	1.08	-	1.01 “Sodium Hydroxide, without water, in 50% solution state (GLO)/ Conseq, S”
Wastewater	kg	N/A	1700	5030	2100	5420 -
Salt (NaCl)	kg	N/A	29.28	128.43	25.94	140.80 “Sodium chloride”
COD	kg	N/A	22.18	25.34	22.18	7.60 “COD (Chemical Oxygen Demand) (RER)”
TOC	kg	N/A	2.02	2.30	2.02	0.69 “TOC, Total Organic Carbon”
Phthalate, dioctyl-	mg	N/A	68.00	79.20	68.00	11.88 “Phthalate, dioctyl-“
Ammonia	kg	N/A	0.0123	0.0349	0.0123	0.0244 -
Total P	kg	N/A	0.0113	0.0383	0.0113	0.0287 -
Cr	kg	N/A	0.0008	0.0073	0.0008	0.0066 -
Cu	kg	N/A	0.0015	0.0152	0.0015	0.0137 -
Ni	kg	N/A	0.0015	0.0136	0.0015	0.0123 -
Cd	kg	N/A	0.0007	0.0064	0.0007	0.0057 -
Trichlorobenzenes (TCB)	µg	N/A	7603	10771	7603	4308 -

Emissions
to Water- Literature
data

Table 5.4 (cont'd)

Membrane Treatment Stage							
Scenario 2.a - Baseline		Scenario 2.1	Scenario 2.2	Scenario 2.3			
Material	Unit	UF	NF	UF	NF	Database Description	Data Source
1,2,3,5 Tetrachlorobenzenes (TECB)	µg	N/A	7258	10282	7258	4113	“Benzene, 1,2,3,5-tetrachloro-“
Pentachlorobenzenes (PCB)	µg	N/A	2304	3264	2304	1306	“Benzene, pentachloro-“
Hexachlorobenzenes (HCB)	µg	N/A	2016	2856	2016	1142	“Benzene, hexachloro-“

5.1.3 Pad Dyeing

The pad-steam method, one of the dyeing techniques operated with padding machinery, was chosen for continuous dyeing of open-width textile pieces. As previously mentioned in [Section 4.3](#), a total of four scenarios were developed for pad-steam reactive dyeing, three of which were membrane scenarios. The total feed flow rate for all pad-steam dyeing scenarios was determined as 18 m³/h, which is the total wastewater flow rate from the dye bath, hot rinsing, and soap washing steps. In addition to flow rate, feed wastewater salt concentration was entered into the software as 22.2 g/L.

5.1.3.1 Scenario 3.a – Pad Baseline

All dyeing, washing, and rinsing wastewater is directly discharged in the baseline scenario. The total amount of wastewater resulting from dyeing and the subsequent hot rinsing, soap washing, and warm rinsing stages was determined as 24 m³ per 1 ton of fabric. The inventory data for Scenario 3.a is given in Table 5.5.

5.1.3.2 Scenario 3.1 (Direct UF)

As in other direct UF scenarios, the IP-51XP module was used in this scenario. The total feed flow rate to the UF system was determined as 18 m³/h. In Figure 5.11, the general representation of the designed UF treatment system is given.

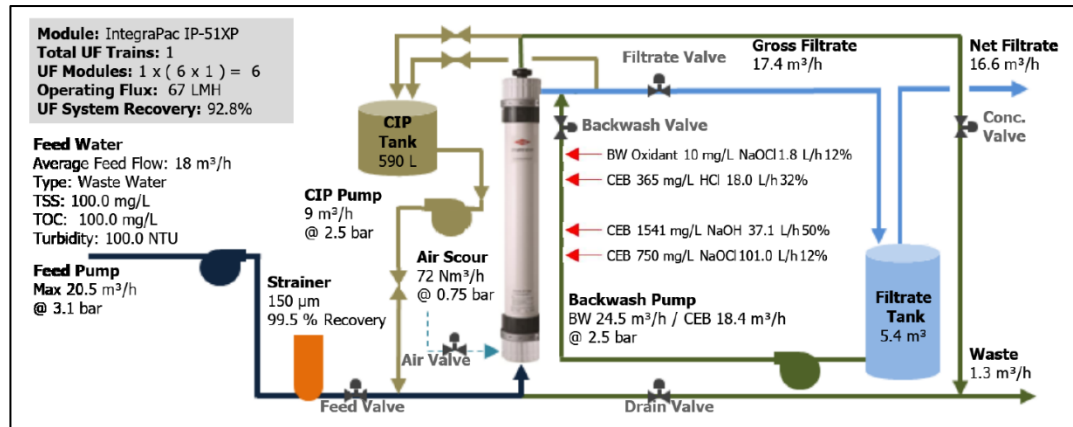


Figure 5.11. Scenario 3.1 – Direct UF System for Pad Dyeing Wastewater

The system configuration was made to have 6 UF modules in 1 train, which allowed to obtain 92.8% system recovery. Correspondingly, the flow rate of permeate was calculated as 16.6 m³/h, and that of concentrate was calculated as 1.3 m³/h. The inventory data, after the reuse, for the reactive dyeing process of Scenario 3.1 is given in Table 5.5, and that of UF treatment is given in Table 5.6. The mass balance flow chart for water and salt is given in Figure C. 7 in APPENDIX C.

5.1.3.3 Scenario 3.2 (Direct NF)

A four-stage NF system with 35% concentrate recycle was designed for UF+NF treatment scenario. The system configuration was made to have 3 pressure vessels (PV) in stage 1, 2 PVs in stage 2, 1 PV in stage 3, and 1 PV in stage 4. 6 elements, which are NF modules, are placed in each PV, meaning, the system was designed with a total of 42 elements. In Figure 5.12, the general representation of the designed NF treatment system is given.

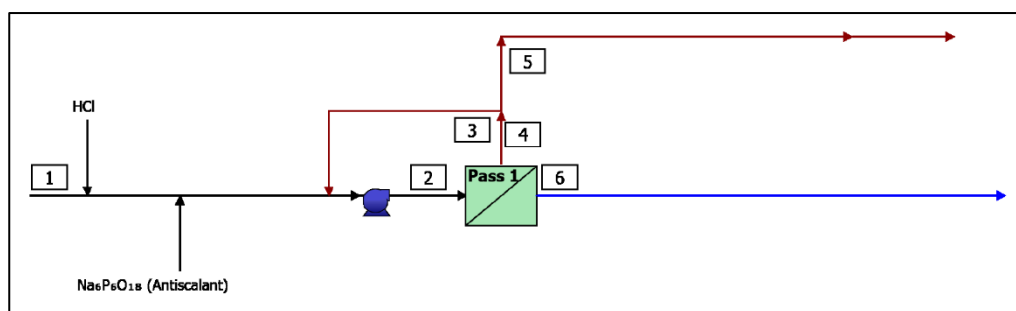


Figure 5.12. Scenario 3.2 – Direct NF System for Pad Dyeing Wastewater

This system allowed 74.1 % recovery, which is comparatively lower than the recovery efficiencies in the jet and jigger dyeing scenarios. Having the lowest wastewater volume and the highest NaCl concentration in the feed, it was an expected result to obtain lower recovery in pad dyeing scenarios. The permeate of the system was calculated as 13.3 m³/h, and the concentrate flow rate was determined as 5.67 m³/h. Based on the results of membrane simulations, inventory data for Scenario 3.2 was generated. The inventory data, after the reuse, for the reactive dyeing process of Scenario 3.2 is given in Table 5.5, and that of NF treatment is given in Table 5.6. The mass balance flow chart for water and salt is given in Figure C. 8 in APPENDIX C.

5.1.3.4 Scenario 3.3 (Combined UF+NF)

A simple flow diagram generated by WAVE of the combined UF+NF system for Scenario 3.3 is presented in Figure 5.13. The overall permeate recovery rate of the system was calculated as 67.5%. The mass balance flow chart for water and salt is given in Figure C. 9 in APPENDIX C.

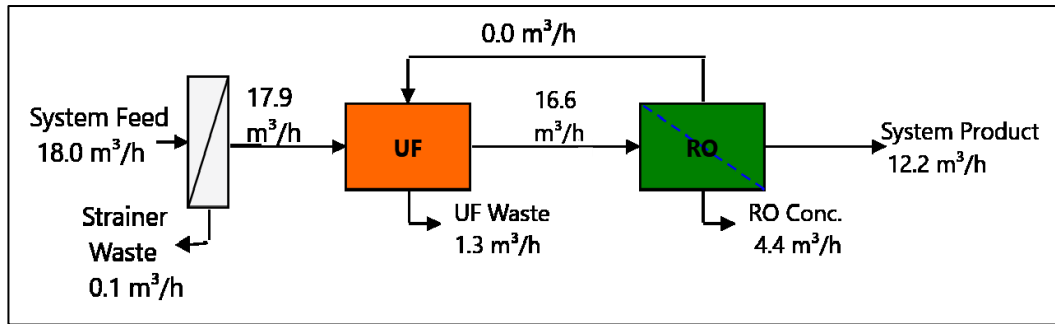


Figure 5.13. Scenario 3.3 - UF+NF Treatment System for Pad Dyeing

UF Pretreatment Design

In this scenario, the IntegraFlux SFP-2860XP module was chosen for the UF pretreatment. In Figure 5.14, the general representation of the designed UF treatment system for the UF+NF combined scenario is given.

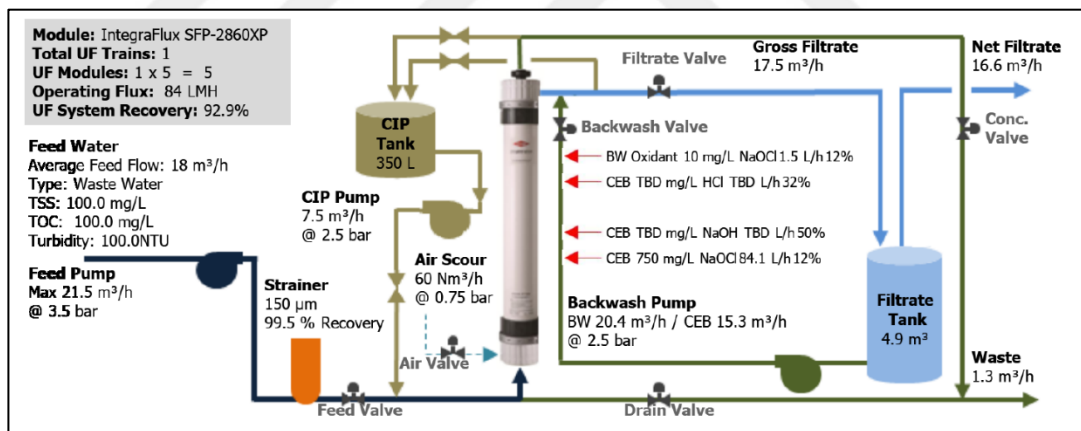


Figure 5.14. Scenario 3.3 – UF Pretreatment System for Jigger Dyeing Wastewater

The system configuration was made to have 5 UF modules in 1 train, which allowed to obtain 92.9% system recovery. Therefore, while the permeate was calculated as $16.6 \text{ m}^3/\text{h}$, the flow rate of waste was determined as $1.3 \text{ m}^3/\text{h}$.

NF Treatment Design

A four-stage NF system with 35% concentrate recycle was designed for UF+NF treatment scenario. The system configuration was made to have 3 pressure vessels (PV) in stage 1, 2 PVs in stage 2, 1 PV in stage 3, and 1 PV in stage 4. 6 elements, which are NF modules, are placed in each PV, meaning, the system was designed with a total of 42 elements. In Figure 5.15, the general representation of the designed NF treatment system is given.

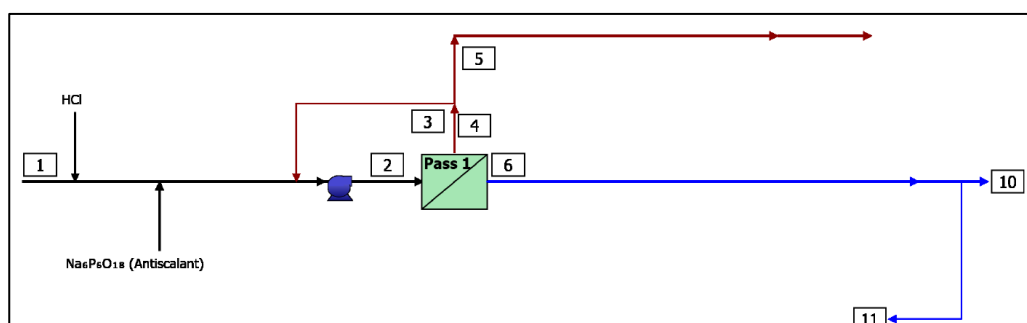


Figure 5.15. Scenario 3.3 – NF System for Pad Dyeing Wastewater

This system allowed 75.5 % recovery. The permeate of the system was calculated as $16.9 \text{ m}^3/\text{h}$, while the flow rate of the concentrate was determined as $5.42 \text{ m}^3/\text{h}$.

The membrane design results from WAVE and the reactive dyeing inventory from the literature together formed the life cycle inventory of Scenario 3.3. The inventory data, after the reuse, for the reactive dyeing process of Scenario 3.3 is given in Table 5.5, and that of UF pretreatment and NF treatment is given in Table 5.6.

Table 5.5. Reactive Dyeing Inventory of Pad Dyeing Scenarios (per 1 ton of fabric dyed)

Material	Reactive Dyeing Stage					Database Description
	Unit	Scenario	Scenario	Scenario	Scenario	
		3.a - Baseline	3.1	3.2	3.3	
Softened water	kg	24000	7400	10700	11800	“Water, completely softened, (RER) /water production/Conseq, S”
Reactive dye (Reactive Orange 12)	kg	50.00	50.00	50.00	50.00	-
Salt (NaCl)	kg	400.00	31.51	144.76	171.48	“Sodium chloride, powder (GLO)/market for/Conseq, S”
Sodium carbonate	kg	20.00	20.00	20.00	20.00	“Sodium carbonate, powder (GLO)/market for/Conseq, S”
NaOH	kg	10.00	10.00	10.00	10.00	“Sodium hydroxide, without water, in 50% solution state (GLO)/market for/Conseq, S”
Surfactant	kg	19.00	19.00	19.00	19.00	“Non-ionic surfactant (GLO)/market for/Conseq, S”
Urea	kg	30.00	30.00	30.00	30.00	“Urea (RER)/market for urea/Conseq, S”
Soap	kg	20.00	20.00	20.00	20.00	“Soap (GLO)/market for/Conseq, S”

Inputs

- BESTÜ Project Data
(Textile mills in Turkey)
- EIA reports of Turkish textile mills

Table 5.5 (cont'd)

Reactive Dyeing Stage						
Material	Unit	Scenario 3.a - Baseline	Scenario 3.1	Scenario 3.2	Scenario 3.3	Database Description
Steam	kg	4000	4000	4000	4000	"Steam, in chemical industry (RER)/production/ Conseq, S"
Electricity	kWh	100.00	100.00	100.00	100.00	"Electricity, high voltage (GLO)/market group for/Conseq, S"
Wastewater	kg	24000	6000	6000	6000	-
Salt (NaCl)	kg	400.00	0	0	0	"Sodium chloride"
COD	kg	26.40	2.64	2.64	2.64	"COD (Chemical Oxygen Demand) (RER)"
TOC	kg	2.40	0.24	0.24	0.24	"TOC, Total Organic Carbon"
Diethyl phthalate	mg	60.00	0	0	0	"Phthalate, dioctyl-"
Ammonia	kg	0.0410	0	0	0	-
Total P	kg	0.0450	0	0	0	-
Cr	kg	0.0081	0	0	0	-
Cu	kg	0.0154	0	0	0	-
Ni	kg	0.0151	0	0	0	-
Cd	kg	0.0067	0	0	0	-

Emissions to Water

- Literature data

Table 5.5 (cont'd)

Reactive Dyeing Stage					
Material	Unit	Scenario 3.a - Baseline	Scenario 3.1	Scenario 3.2	Scenario 3.3
Database Description					
Trichlorobenzenes (TCB)	µg	12672	0	0	0
1,2,3,5-Tetrachlorobenzenes (TECB)	µg	12096	0	0	0
Pentachlorobenzenes (PCB)	µg	3840	0	0	0
Hexachlorobenzenes (HCB)	µg	3360	0	0	0
CO	kg	0.82	0.82	0.82	0.82
SO ₂	kg	0.87	0.87	0.87	0.87
NO _x	kg	1.13	1.13	1.13	1.13
Dust	kg	0.23	0.23	0.23	0.23
VOC	kg	0.41	0.41	0.41	0.41

- BESTÜ Project Data
(Textile mills in Turkey)
- EIA reports of Turkish textile mills
- Literature data

Emissions to Air

“Particulates, < 2.5 µm”

“VOC, volatile organic compounds as C”

Table 5.6. Membrane Treatment Inventory of Pad Dyeing Scenarios (per 1 ton of fabric dyed)

Membrane Treatment Stage						
Scenario 3.a - Baseline		Scenario 3.1	Scenario 3.2	Scenario 3.3		
Material	Unit	UF	NF	UF	NF	Data Source
HCl	kg	N/A	0.30	0.30	0.20	“Hydrochloric acid, without water, in 30% solution state (RER)/market for/Conseq, S”
Sodium hypochlorite (NaOCl)	kg	N/A	-	6.39	-	“Sodium hypochlorite, without water, in 15% solution state (GLO)/market for/Conseq, S”
Citric acid	kg	N/A	-	0.23	-	“Citric acid (GLO)/market for/Conseq, S”
NaOH	kg	N/A	-	2.29	-	“Sodium hydroxide, without water, in 50% solution state (GLO)/market for/Conseq, S”
Electricity	kWh	N/A	138.60	24.44	139.60	“Electricity, high voltage (GLO)/market group for/Conseq, S”

Inputs

- WAVE Software results

Table 5.6 (cont'd)

Membrane Treatment Stage						
Scenario 3.a - Baseline		Scenario 3.1	Scenario 3.2	Scenario 3.3		
Material	Unit	UF	NF	UF	NF	Data Source
Phosphoric acid	kg	N/A	0.49	-	0.45	“Phosphoric acid, industrial grade, without water, in 85% solution state (GLO)/market for/Conseq, S”
NaOH (for NF)	kg	N/A	0.81	-	0.75	“Sodium Hydroxide, without water, in 50% solution state (GLO)/Conseq, S”
Wastewater	kg	N/A	4670	1300	4450	- WAVE Software results
Salt (NaCl)	kg	N/A	144.76	31.51	140.00	“Sodium chloride”
COD	kg	N/A	19.01	16.63	5.70	“COD (Chemical Oxygen Demand) (RER)”
TOC	kg	N/A	1.73	1.51	0.52	“TOC, Total Organic Carbon”
Phthalate, dioctyl-	mg	N/A	59.40	51.00	8.91	“Phthalate, dioctyl-”
Ammonia	kg	N/A	0.0349	0.0123	0.0244	-
Total P	kg	N/A	0.0383	0.0113	0.0287	-
Cr	kg	N/A	0.0073	0.0008	0.0066	-

Emissions to Water

- Literature data

Table 5.6 (cont'd)

Membrane Treatment Stage							
Material	Unit	Scenario 3.a - Baseline	Scenario 3.1	Scenario 3.2	Scenario 3.3		
		-	UF	NF	UF	NF	Database Description
Cu	kg	N/A	0.0015	0.0152	0.0015	0.0137	-
Ni	kg	N/A	0.0015	0.0136	0.0015	0.0123	-
Cd	kg	N/A	0.0007	0.0064	0.0007	0.0057	-
Trichlorobenzenes (TCB)	µg	N/A	7603	10771	7603	4308	-
1,2,3,5-Tetrachlorobenzenes (TECB)	µg	N/A	7258	10282	7258	4113	"Benzene, 1,2,3,5-tetrachloro-"
Pentachlorobenzenes (PCB)	µg	N/A	2304	3264	2304	1306	"Benzene, pentachloro-"
Hexachlorobenzenes (HCB)	µg	N/A	2016	2856	2016	1142	"Benzene, hexachloro-"

5.2 Life Cycle Impact Assessment Results

In this section, the LCA results of three different membrane treatment scenarios and direct discharge scenarios created for three different dyeing methods are presented and discussed. While the normalized LCA results are presented in APPENDIX E, the contributions of the processes to the mid-point impact categories are given in APPENDIX F, and the contributions of the processes to the end-point effect categories are given in APPENDIX G. The tree diagrams of all 12 scenarios are presented in APPENDIX H.

5.2.1 Jet Dyeing LCA Results

The LCA results of membrane filtration treatment scenarios were compared to that of the baseline scenario for the jet reactive dyeing. Impact assessment results were first compared on an end-point basis, as seen in Figure 5.16.

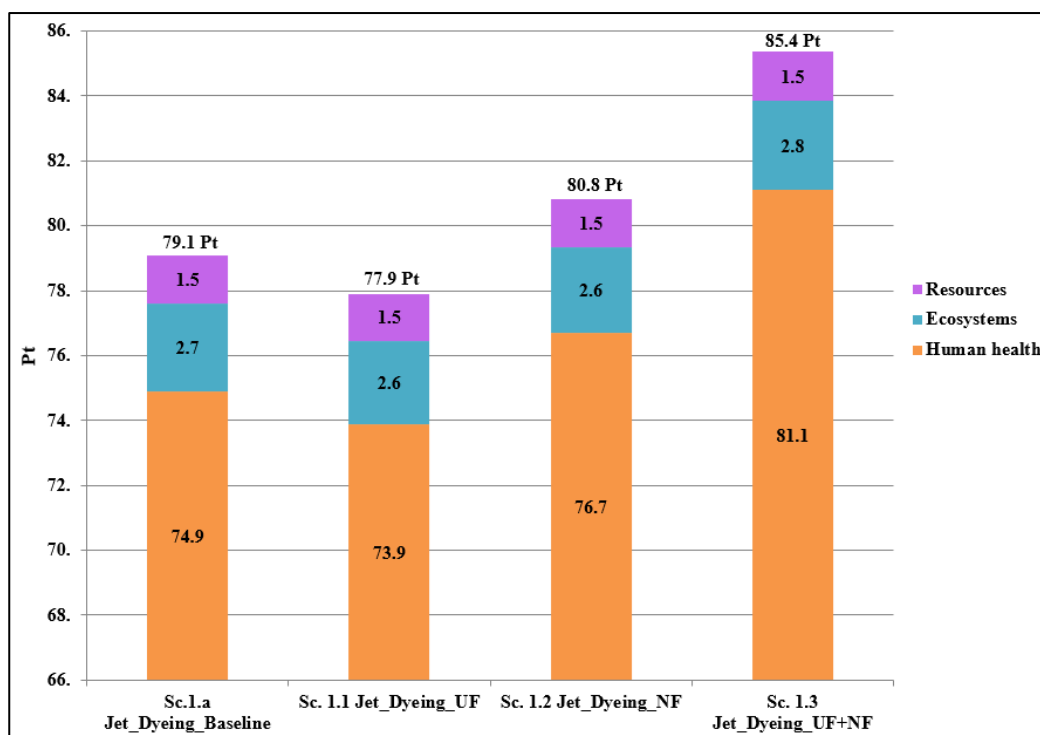


Figure 5.16. Comparative End-Point Environmental Impacts for Jet Dyeing

From the results, it is evident that all four scenarios have the highest impact on the “Human Health” end-point impact category. The mid-point categories that can be grouped under the "Human Health" impact category are given in Table D. 2 in APPENDIX D; accordingly, it is expected to see higher impacts on the human health-related mid-point categories. The single-score comparison results for mid-point impact categories are given in Figure 5.17.

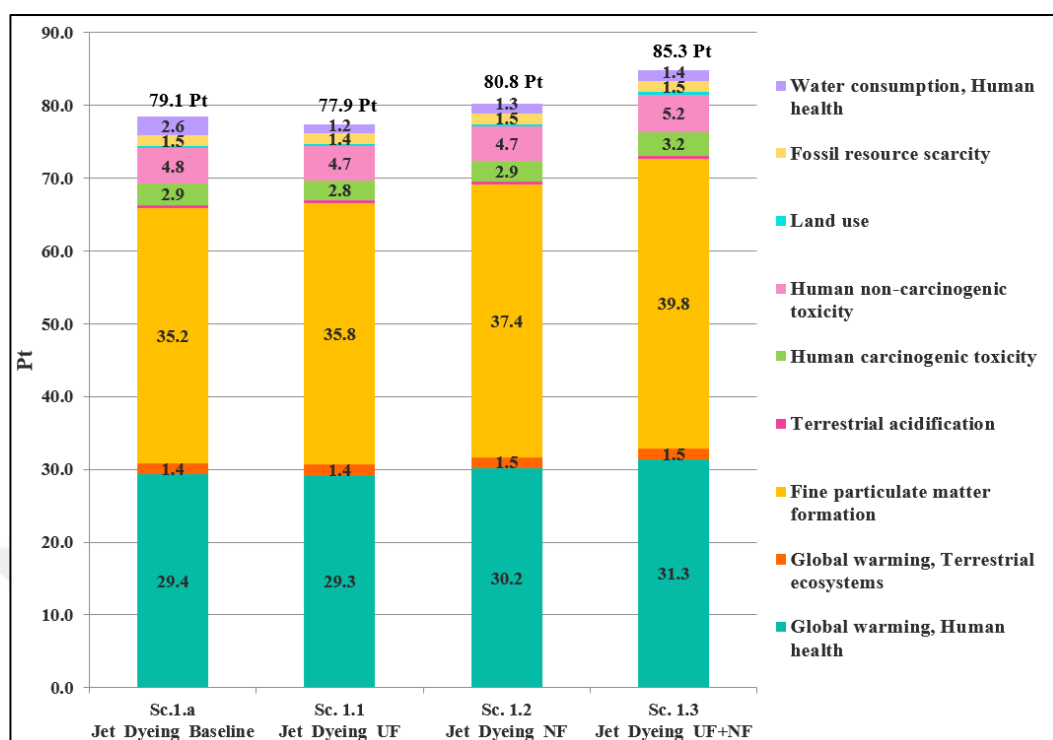


Figure 5.17. Comparative Mid-Point Environmental Impacts for Jet Dyeing

The results confirm that the highest impacts are observed on human health-related mid-point categories. The comparative single-score results show that for each scenario, the highest contribution is to the “Fine particulate matter formation (FPMF)” impact category. This result was attributed to the dust, SO₂, and NO_x formed during the dyeing stage of each scenario. The second highest impact was observed in the “Global warming, Human health (HGWP)” impact category, which results from the greenhouse gas emissions to the atmosphere. The main contributor to the HGWP is the electricity consumption in all dyeing and membrane treatment stages and the steam production and consumption in the dyeing stage. The damage pathway between global warming and human health is formed by considering the adverse effects of global temperature increase on diseases and natural disasters such as floods and droughts. The other two impact categories with relatively lower contributions are “Human non-carcinogenic toxicity (HT non-carcinogenic)” and

“Human carcinogenic toxicity (HT carcinogenic)” categories, which stem from the use of chemicals in the dyeing stage.

The cumulative single-score results indicate that Scenario 1.3 (UF+NF treatment) has the highest overall impact on the environment. The main reason for this difference is this scenario’s contribution to the FPMF and HGWP impact categories. This result highlighted the need to analyze the main process input and outputs contributing to the top two impact categories: FPMF and HGWP.

The LCA study proceeded into detail on the basis of process inputs in order to determine the parameters that contribute the most to the FPMF in the scenarios. The results can be seen in Figure 5.18.

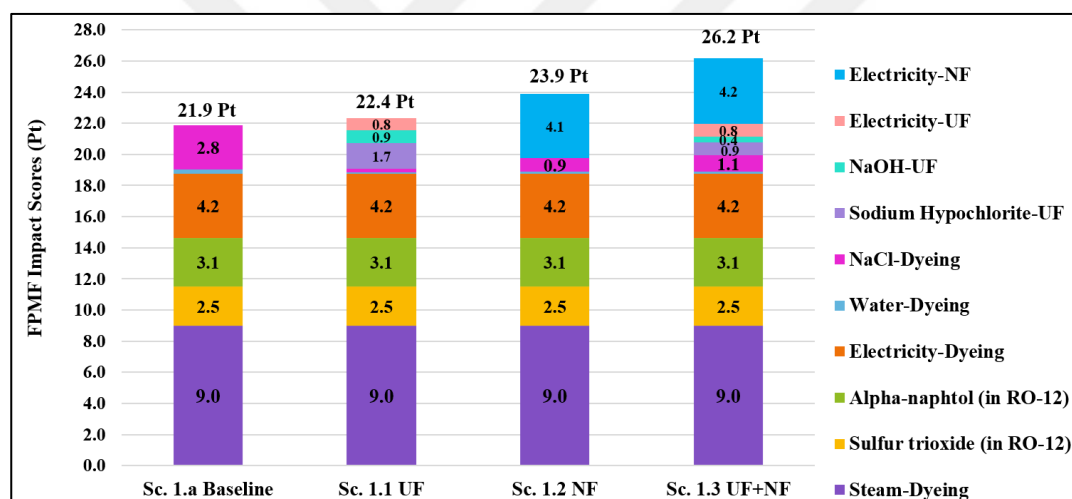


Figure 5.18. Main Contributors to FPMF Impact Category for Jet Dyeing

As can be seen from Figure 5.18, the contribution of the first four raw materials, which are steam, sulfur trioxide, alpha-naphthol present in Reactive Orange-12, and electricity to the impact category, is the same for all four scenarios. These four raw materials are the main inputs of the dyeing stage. It can be clearly seen that the highest contribution to the FPMF category belongs to steam, which is a parallel finding with the LCA study of Liu et al. (2020), which was conducted for textile manufacturing processes. Although the contribution of water use is significantly

lower than other parameters, the impact of reuse can be observed from the share of water in membrane treatment scenarios. The same trend can also be seen for salt (NaCl) use, represented with pink bars, with a more noticeable difference. It is evident that due to its high salt and water permeability, the UF treatment and the reuse of the permeate decreased the salt consumption the most in the dyeing process.

After this point, it is clearly seen that the difference in the contribution of the scenarios to the FPMF category is due to the use of chemicals and energy in the membranes. Particularly, the impact of using NaOH for UF membranes stands out from the impacts of other chemicals.

Main process contributions to HGWP mid-point impact category are presented in Figure 5.19.

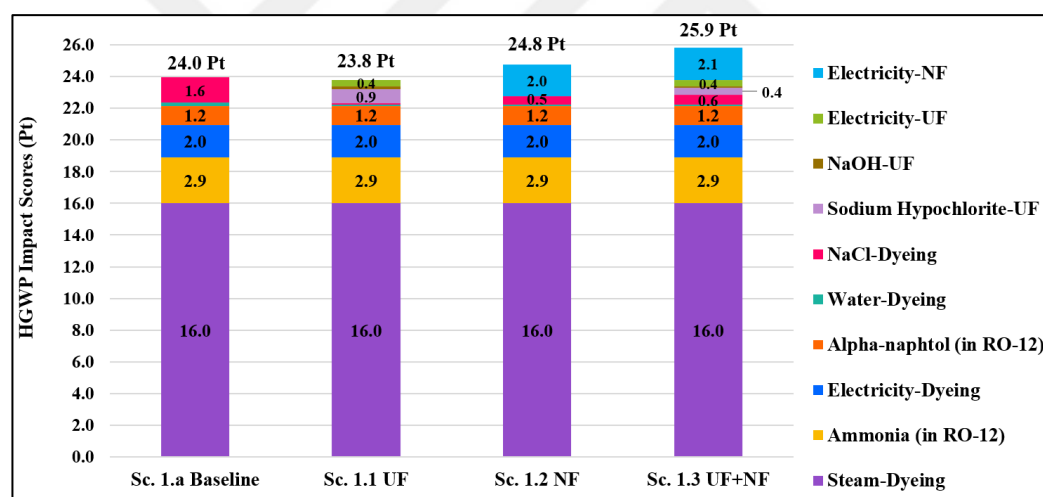


Figure 5.19. Main Contributors to HGWP Impact Category for Jet Dyeing

It is seen from Figure 5.19 that for the HGWP category, the impacts of the dyeing process were found to be the same in all scenarios. This is an expected result as the amount of main raw materials used for dyeing is the same in all scenarios, except the amount of water and salt. Although the impact contribution differences in water and salt use are reflected in the graphics, their impacts are relatively low. Similar to the FPMF category, the parameters that make the main difference in the HGWP impact

category are the chemicals and energy used in the membranes. Therefore, it can be concluded that Scenario 1.3 (UF+NF) has the highest impact due to the cumulative energy and chemical consumption in UF and NF membrane treatment stages.

5.2.2 Jigger Dyeing LCA Results

The end-point impact analysis of the LCA results of the jigger dyeing scenarios, which can be seen in Figure 5.20, showed that as in jet dyeing, the highest impact is in the Human Health category and the scenario with the most impact is Scenario 2.3 (UF+NF).

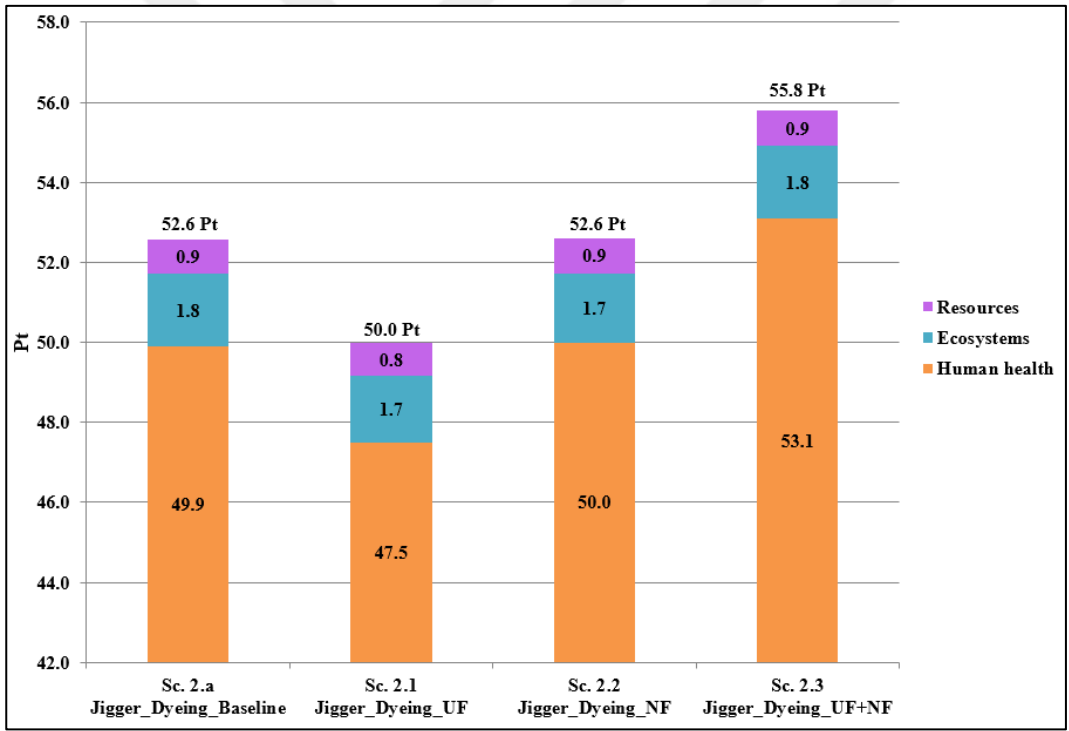


Figure 5.20. Comparative End-Point Environmental Impacts for Jigger Dyeing

In jet dyeing, while the total impact of the NF treatment scenario is obviously higher than the Baseline scenario, in jigger dyeing, the total impacts of these two scenarios are the same. This difference is attributed to the relatively less energy consumption

in membrane treatment scenarios of jigger dyeing. For further analysis, the single-score comparison results for mid-point impact categories were evaluated and given in Figure 5.21.

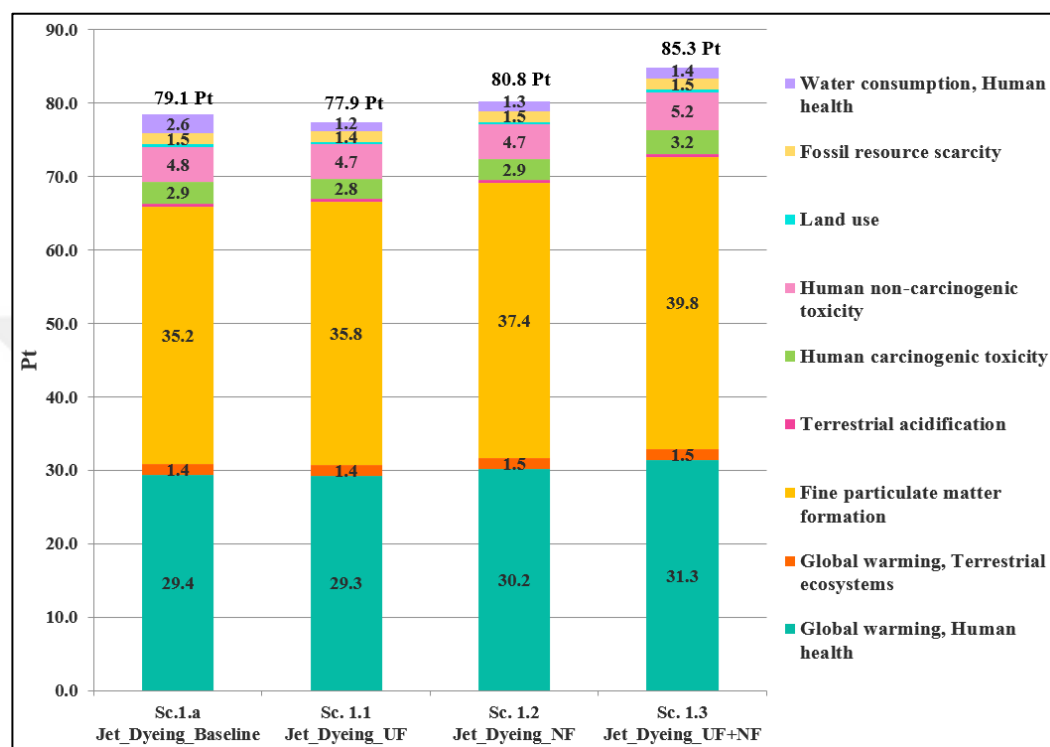


Figure 5.21. Comparative Mid-Point Environmental Impacts for Jigger Dyeing

The most obvious finding to emerge from the analysis is that the highest contributions are to the HGWP and FPMF mid-point impact categories. Compared to the results of jet dyeing scenarios, it can be stated that the overall environmental impacts of jigger dyeing are significantly lower than that of jet dyeing. This output can be associated with the use of considerably lower electricity, steam, and water in jigger dyeing and the decrease in energy and chemical consumption in membrane treatments due to less wastewater production. Nevertheless, the FPMF and HGWP categories, where significantly higher impacts were observed, need further analysis.

Analysis of the input and output contributions to the FPMF impact category is given in Figure 5.22.

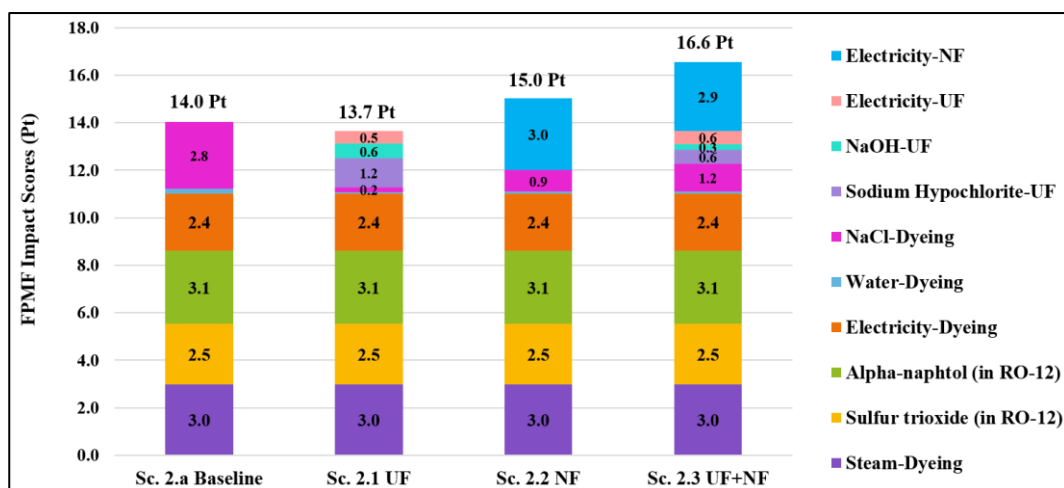


Figure 5.22. Main Contributors to FPMF Impact Category for Jigger Dyeing

The findings from Figure 5.22 indicate that the significant reduction in salt use in the membrane scenarios reduces the contribution to the FPMF category by 2.6 Pt for Scenario 2.1, 1.90 Pt for Scenario 2.2, and 1.60 Pt for Scenario 2.3. The positive impact of lower steam consumption in jigger dyeing than in other dyeing methods can also be seen from the results. However, the use of chemicals and the energy consumption in membrane treatment cause an increase in the overall impact.

The single-score impact analysis for the HGWP mid-point category showing individual contributions of process inputs is given in Figure 5.23.

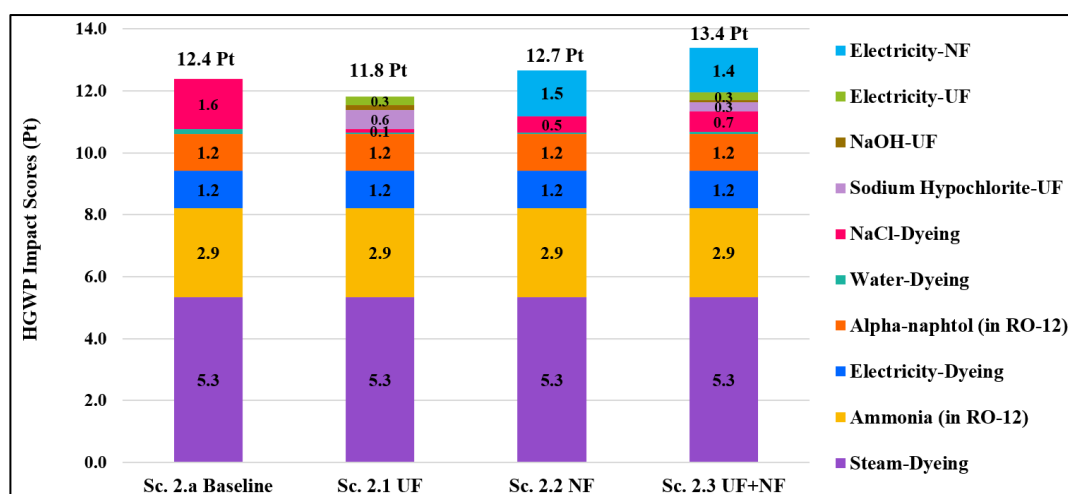


Figure 5.23. Main Contributors to HGWP Impact Category for Jigger Dyeing

The HGWP impact category analysis showed that in scenarios involving the NF treatment process, the contribution to environmental impacts is high due to significant energy consumption. The results show that Scenario 2.2 (NF) and Scenario 2.3 (UF+NF) have more overall impact compared to the baseline scenario. The outputs of the LCA study suggest that Scenario 2.1 UF membrane treatment has the least environmental impact.

5.2.3 Pad Dyeing LCA Results

The LCA results for the pad dyeing scenarios were first compared on end-point impact categories. Figure 5.24 shows that the point contribution to the Resource and Ecosystem impact categories are approximately the same for each scenario. The difference in overall end-point impacts results from the different contributions to the Human Health impact category. As in other dyeing scenarios, the highest impact among the pad dyeing scenarios belongs to the UF+NF membrane treatment scenario (Scenario 3.3).

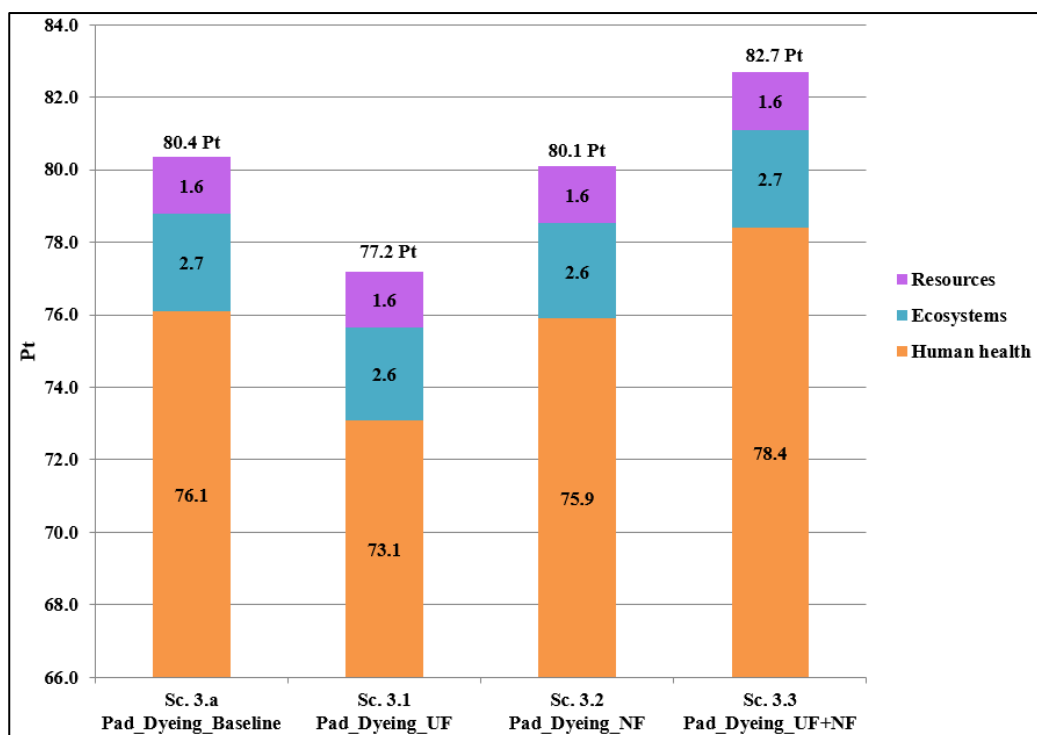


Figure 5.24. Comparative End-Point Environmental Impacts for Pad Dyeing

Unlike other dyeing scenarios, the NF treatment scenario (Scenario 3.2) has a slightly lower overall impact than the baseline scenario (Scenario 3.a). In order to show the differences in total impacts of the scenarios, total point scores are indicated in Figure 5.24. In order to determine the possible reasons for this difference, the results of the mid-point impact category were evaluated, and the results are given in Figure 5.25.

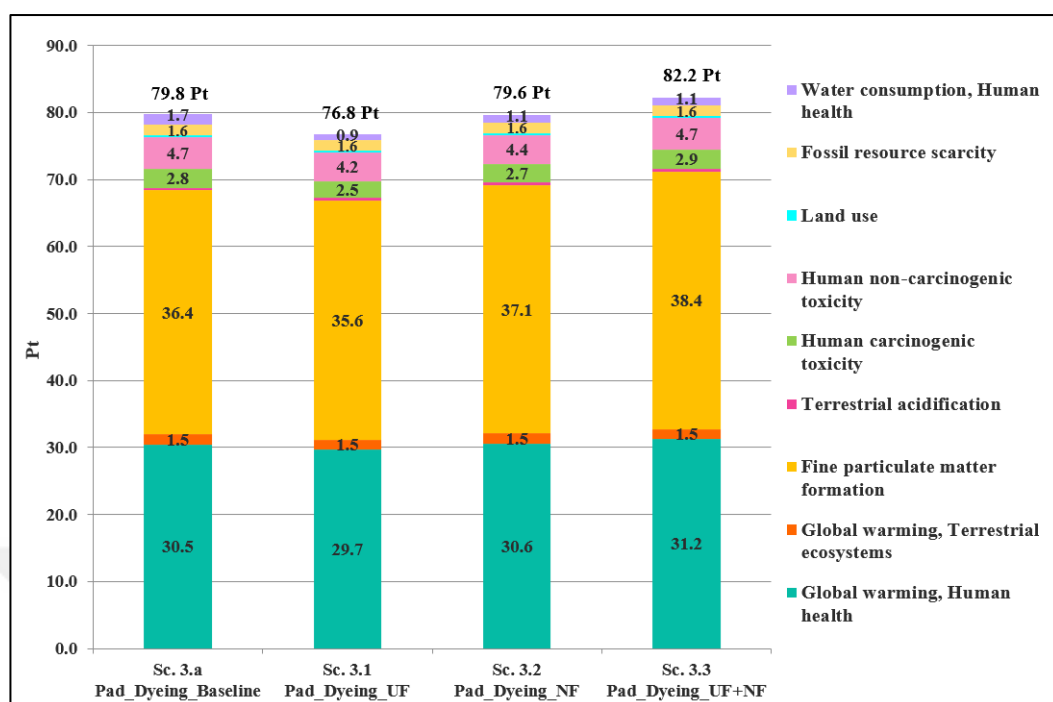


Figure 5.25. Comparative Mid-Point Environmental Impacts for Pad Dyeing

Parallel to the other dyeing scenarios, it was observed that the highest contribution was made to the FPMF and HGWP categories in the pad dyeing scenarios. However, water consumption and thus wastewater generation are much lower in pad dyeing compared to other dyeing methods, and this is reflected in the results. Significantly less energy and chemicals are consumed in the NF and UF membrane treatment of pad dyeing wastewater with a low flow rate. Therefore, the contribution of the energy consumption of the membranes to the FPMF and HGWP categories in pad dyeing is much lower than in other dyeing scenarios.

As in other scenarios, process, input, and output contribution evaluations for the FPMF and HGWP impact categories were made for the pad dyeing scenarios, and the results for the FPMF category are presented in Figure 5.26.

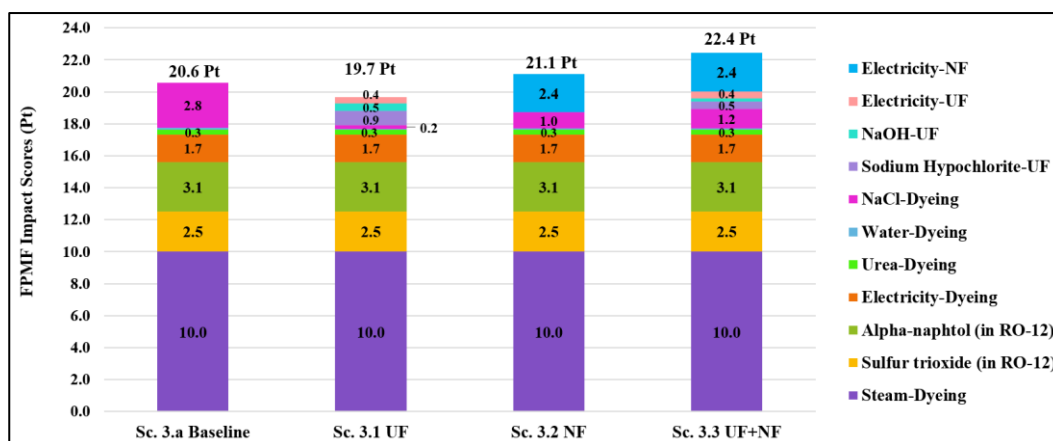


Figure 5.26. Main Contributors to FPMF Impact Category for Pad Dyeing

The results show that the highest contribution to the FPMF category is seen in the NF and UF+NF scenarios, as expected, and the reason for this is the energy consumption, particularly in NF treatment.

The single-score impact analysis for the HGWP mid-point category showing individual contributions of process inputs is given in Figure 5.27.

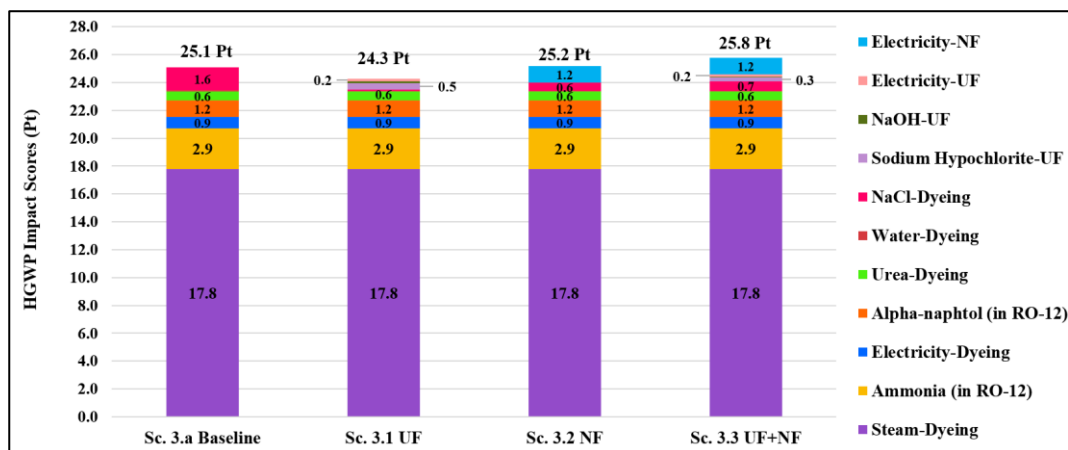


Figure 5.27. Main Contributors to HGWP Impact Category for Pad Dyeing

Results of the analysis showed that the overall contribution of the scenarios to the HGWP category is quite similar to each other. The UF treatment scenario has the lowest impact, as the reuse of high flow, salt-rich permeate reduces water and salt

consumption in dyeing, and the system has relatively low energy consumption. In contrast to other dyeing methods, pad-steam dyeing utilizes urea, which is reflected in the results. As can be seen, it has a minor contribution to the overall impact, accounting for only about 2%.

If the results of all impact analyzes are evaluated, it is seen that the best scenario in terms of environmental impact is the UF treatment scenario (Scenario 3.1). However, unlike the other dyeing scenarios, the NF treatment scenario (Scenario 3.2) can also be considered to apply in terms of its environmental impact since it has a lower environmental impact than the baseline scenario (Scenario 3.a).

5.2.4 A Summary of LCA Results for Alternative Dyeing Techniques

In Figure 5.28, the LCA results for all alternative dyeing scenarios are given on end-point impact categories in order to see how the impacts alter as the dyeing technique changes in comparison to its direct discharge scenario. As shown, for all three dyeing techniques, the impacts of direct wastewater discharge are higher than direct UF treatment and lower than UF+NF treatment. However, the impacts of direct NF treatment were slightly higher than the direct discharge for jet dyeing, equal for jigger dyeing, and lower for the pad-steam dyeing process. On the other hand, the reactive dyeing by the jigger dyeing technique was found to be with almost 40 % lower impacts than the other two dyeing techniques. This reduction in environmental impacts was attributed to significantly lower steam consumption in the jigger dyeing technique.

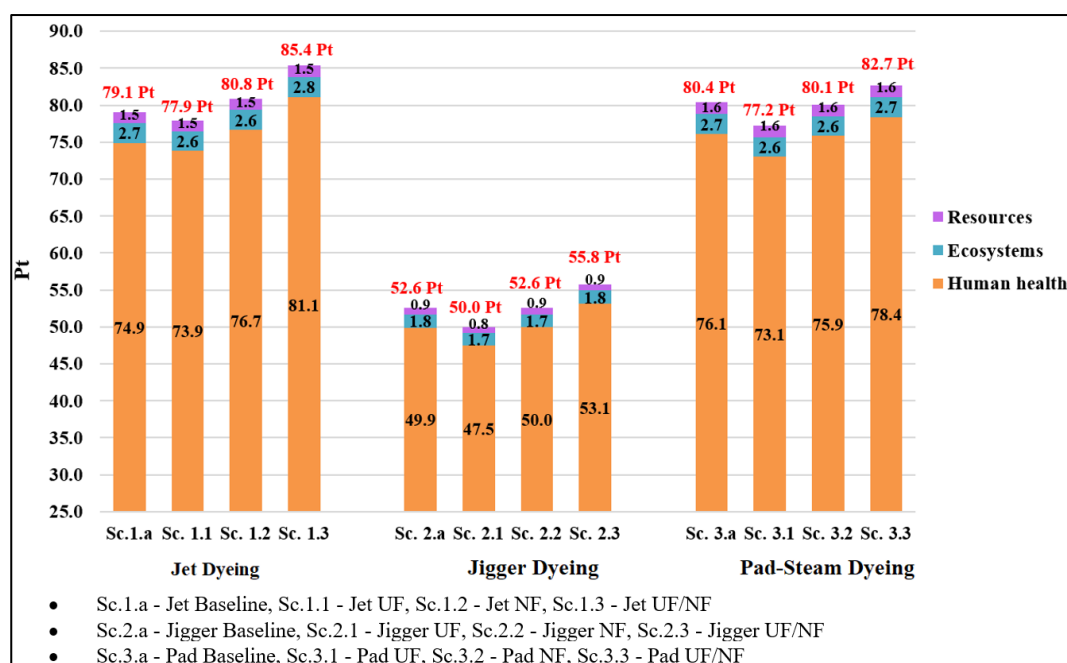


Figure 5.28. Comparative End-Point Impacts for Alternative Dyeing Techniques

Figure 5.28 shows that regardless of the dyeing technique, the highest environmental impact in all dyeing techniques is in the "Human Health" impact category, followed by the "Ecosystems" category. It is clear that the most important factor influencing the overall environmental impacts of dyeing techniques is the production and consumption of steam, which makes jigger dyeing have the lowest impact. This outcome implies that reducing the amount of steam utilized is critical in managing environmental impacts and thus saving energy. As suggested in the study by Hasanbeigi & Price (2012), using a steam coil rather than direct steam in the batch dyeing results in annual energy savings for a textile plant of 4,580 GJ, which further supports this finding.

As mentioned above, UF-only treatment appears as the most sustainable alternative among the membrane filtration scenarios considered. However, an important criterion that should be taken into account is the quality of the permeate from this process. The most important factor to be considered in this application is the shade of color to be applied in the dyeing process, where the permeate from UF will be

reused. The study carried out by Allégre et al. (2006) pointed out that the dyeing wastewater treated with UF-only may not be suitable for reuse in the dyeing process. In the study of Chollom et al. (2015), in cases where the color removal as a result of wastewater treatment is not sufficient, it is recommended to reuse the treated wastewater for medium or dark-shade dyeing rather than light-shade dyeing.



CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Reactive dyeing, commonly used on cotton fabrics, requires a significant amount of salt and other auxiliary chemicals for dye fixation on the fabric. The wastewater from this process contains a high concentration of color, COD, TDS, and salt, along with heavy metals and AOX species, with some adverse effects on the environment. Therefore, the reactive dyeing wastewater needs to be managed in a sustainable way to minimize its impacts. Towards this end, reusing reactive dyeing wastewater and salt in the dyeing process via membrane separation is suggested as a BAT alternative.

In the present study, a comparison of the reuse scenario with the direct wastewater discharge scenario was made by following an LCA approach. Three distinct reactive dyeing methods were considered: jet dyeing for rope pieces and jigger and pad-steam dyeing for open-width pieces. Thereafter, three different membrane treatment scenarios (UF, NF, and UF+NF) were devised using WAVE software. WAVE was used to obtain the inventory data for membrane treatment of the wastewater generated by each reactive dyeing technique since there is no real data for such alternative reuse applications, which is an important novelty of this study. The results of the membrane and the direct discharge scenarios were compared with the aid of SimaPro LCA software.

From the results of the LCA study, it can be drawn that production and use of steam have the highest environmental impact in all dyeing methods and scenarios. This finding implies that efficiency measures to be taken in terms of energy use can significantly improve the dyeing process's environmental impacts.

Following steam usage, the main chemicals in the reactive dye (Reactive Orange 12), sulfur trioxide, ammonia, and alpha-naphthol, significantly contribute to the total environmental impact of reactive dyeing. It appeared that using reactive dyes with a

high fixation rate or the application of modifications would increase the fixation rate in the dyeing process and, in turn, significantly improve the dyeing process's environmental impacts.

The LCA results of the membrane treatment scenarios indicated that pressure-driven membrane applications consume a significant amount of electrical energy. In direct proportion to the amount of pressure applied, the energy consumption of NF treatment and thus its contribution to the overall environmental impact is greater than that of UF treatment. It is worth pointing out that UF-only treatment provided approximately 93% reduction in salt consumption in reactive dyeing. Considering this outcome, the UF treatment scenario with low energy consumption and significant savings in salt consumption has been a viable scenario for all dyeing methods.

As the LCA results revealed, the most significant impact is in the FPMF and HGWP impact categories. The treatment of reactive dyeing wastewater with UF and reusing water and salt in the dyeing process is the best technique in terms of environmental impacts. It should be noted that successful dyeing may not be attained if the permeate obtained after UF-only treatment is reused in light-shade dyeing. UF treatment will not be sufficient, particularly if light-shade dyeing will follow medium or dark-shade dyeing. In this case, the application of NF-only treatment is an option that should not be discounted.

The comparison of the end-point environmental impacts of three different dyeing techniques suggested that regardless of the dyeing technique, the highest environmental impact in all dyeing techniques is in the "Human Health" impact category. Reducing the amount of steam utilized is deemed critical in managing environmental impacts, as the variation in the environmental impacts of the techniques is primarily attributable to the different amounts of steam used.

For the future studies in this study field, the following recommendations are proposed:

- The results of this study suggest that impact assessment results can vary depending on parameters of impact assessment methods, such as allocation percentages and the factors of damage, characterization and normalization. Therefore, a change in these parameters and use of a different impact assessment method will alter the results of the impact assessment, which is an important aspect to consider when interpreting the results of this study.
- It is possible that the accuracy of the findings of this study may be affected by a number of assumptions made through this study. It is recommended to conduct a comprehensive uncertainty analysis for future studies for the data accuracy assurance.
- The lifetimes of the membrane modules can be considered in the future membrane-based water and salt recovery LCA studies.
- The use of different membranes will make a difference in terms of both treatment performance and operational parameters, which will alter the inventory data. These differences have the potential to cause changes in environmental impacts. Therefore, different membranes can also be studied in the future.
- Depending on the choice of reactive dye, there may be differences in environmental impacts due to chemical differences in the structures of the dyes. For this reason, it is recommended to study the environmental impacts of different reactive dyes.
- LCA impact analysis methods do not precisely and thoroughly calculate the toxicity effects of emissions to water. For this reason, a toxicity impact analysis should be conducted together with an LCA study in order to reach a definite conclusion.
- Considering the results of this study, it is evident that the environmental impacts of steam production have a significant share in the total impact. The fact that the energy source to be used in steam production is from renewable sources instead of fossil fuels will make a significant difference in

environmental impact, which is an important point that should be included in the scope of future studies.

- A change in the electricity production mix will change the LCA results. In installation-specific studies, it is recommended that the local electricity production mix is considered in the LCA study.



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APPENDICES

A. Data Collected for Inventory Analysis

Table A. 1. Literature Inventory Data

Category	Unit	Dyeing Process Inputs and Outputs (per 1 ton of fabric dyed)							
		(Zhang et al., 2015)	(Zhang et al., 2018)	(Z. W. Yuan et al., 2013)	(Álvarez et al., 2020)	(Liu et al., 2020)	(Talouizte et al., 2020)	(Jewell, 2017)	(Jewell, 2017)
Dyeing Method	-	-	-	Continuous Pad Dyeing	Jet Dyeing (Batch)	-		Jet Dyeing (Batch)	Continuous Dyeing
Electricity	kWh	1071.90	452.40	62.36				335.91	97.62
Natural gas	MJ			0.03				5914.73	5838.10
Natural gas	GJ							5.89	5.85
Coal	kg	2882.35	3500.00	643.50					
Steam	kg	1581.70						6581.40	4010.03
Water	kg	185620.92	11900.00	27130.00	20000.00	27644.63		106573.64	71333.33
Dyes	kg	50.33	33.00	57.00	35.00	59.03		128.68	18.38
NaCl	kg	1346.41		400.00	600.00			497.67	215.54
Urea	kg					140.50		0.00	
NaOH (lye)	kg							53.10	64.10
Sodium Carbonate	kg			80.00	170.00	219.83		71.94	12.63
Surfactant	kg							4.74	18.86
Water vapor	kg	77777.78							

Table A. 1 (cont'd)

Dyeing Process Inputs and Outputs (per 1 ton of fabric dyed)									
Category	Unit	(Zhang et al., 2015)	(Zhang et al., 2018)	(Z. W. Yuan et al., 2013)	(Alvarez et al., 2020)	(Liu et al., 2020)	(Talouizte et al., 2020)	(Jewell, 2017)	(Jewell, 2017)
Soap	kg			6.00					
NOx	kg	94.77	26.50	0.36				0.02	
CO ₂	kg	7843.14	9350.00	1335.00					
CH ₄	kg			6.40					
Fly ash	kg	43.79		0.48					
Dust	kg		715.00						
Water vapor	kg								
SO ₂	kg	7.84	30.00	1.01				29767.44	13047.62
Wastewater	kg	84313.73	10710.00	27100.00	14000.00	27644.63		69922.48	58285.71
Phosphorus	kg	0.06				0.05	0.02	0.08	0.03
Ammonium	kg					0.05	0.02		
Chromium	kg					4.7E-04	7.0E-04	0.03	0.01
Copper	kg						1.3E-04	0.04	0.01
Nickel	kg						6.7E-04	0.04	0.01
Cadmium	kg			1.5*10 ⁻⁷			3.4E-05	0.02	0.003
AOX	kg								0.07
Hydrocarbons	kg	0.06						0.31	0.20
Dissolved solids	kg	4.58						38.91	0.02
Total nitrogen	kg	5.88				0.21		0.80	0.30
SS	kg			3.33				1.42	0.78
BOD	kg							1.49	0.86
COD	kg	6.54	149.50	30.90				7.12	1.97

Table A. 2. BESTÜ Project Inventory Data (Plant 1-7)

Dyeing Process Inputs and Outputs (per 1 ton of fabric dyed)								
Category	Unit	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7
Dyeing Method	-	HT Jet (Batch) and Pad-batch (Semi-continuous)	HT Jet (Batch) and Pad-batch (Semi-continuous)	HT Jet (Batch) and Pad-batch (Semi-continuous)	HT Jet (Batch) and Pad-batch (Semi-continuous)	HT Jet (Batch) and Pad-batch (Semi-continuous)	-	-
Water	kg	67200.00	57600.00	97200.00	99600.00	101400.00	109800.00	98400.00
Steam	kg	10000.00	13000.00	15000.00	18000.00	13000.00	5000.00	
Electricity	kWh	600.00	1200.00	1200.00	7200.00	1200.00	1800.00	600.00
Auxiliary Chemical	kg	132.00	178.20	208.20	249.60	180.600	103.20	66.00
Dye	kg	35.00	25.00	38.00	41.00	24.000	30.00	33.00
Salt	kg	72.00	2.00	67.00	397.00	136.000		23.00
Wastewater	kg	62400.00	49800.00	94200.00	89400.00	100200.00	99000.00	88800.00
CO	kg	4.80	3.00	6.00	3.60	1.80		0.36
SO ₂	kg	0.18	8.40	1.20	4.80	0.42		0.26
NOx	kg	7.20	19.20	3.00	1.92	12.00		0.29
Dust	kg	0.30	0.06		0.48	0.06		0.60
VOC	kg	0.12		0.02	1.20	0.06		

Table A. 3. BESTÜ Project Inventory Data (Plant 8-15)

Dyeing Process Inputs and Outputs (per 1 ton of fabric dyed)										
Category	Unit	Plant 8	Plant 9	Plant 10	Plant 11	Plant 12	Plant 13	Plant 14	Plant 15	
Dyeing Method	-	HT Jet (Batch) and Pad-batch (Semi-continuous)	HT Jet (Batch)	-	HT Jet (Batch)	-	Pad batch (Semi-continuous) and HT-overflow (Batch)	Pad batch (Semi-continuous) and HT-overflow (Batch)	HT-jet (Batch) and Pad-batch (Semi-continuous)	
Water	kg	36600.00	41400.00	31200.00	76200.00	159000.00	37800.00	93000.00	38146.76	
Steam	kg	11000.00		18000.00	9000.00	18000.00	8000.00	5700.00	6000.00	
Electricity	kWh	600.00	1200.00	1200.00	600.00	4200.00	480.00	480.00	600.00	
Auxiliary Chemical	kg	59.40	111.60	57.00	205.20	259.20	201.60	103.80	76.80	
Dye	kg	22.00	50.00	36.00	43.00	30.00	10.00	5.00	15.00	
Salt	kg	331.00		45.00	413.00	964.00	102.00	48.00	156.00	
Wastewater	kg	36000.00	39000.00	23400.00	68400.00	126600.00	35400.00	84000.00	15449.44	
CO	kg		0.22	0.00	0.90	2.40	2.40	0.42	1.02	
SO ₂	kg		0.02	0.05	0.72	0.60	4.80	7.20	0.04	
NOx	kg		0.38	2.40	2.10	21.00	4.80	0.90	1.50	
Dust	kg		0.60	0.12	0.60	4.20	0.06	0.60	0.04	
VOC	kg		0.06	0.24	1.08	0.00	0.00	0.06	0.60	

Table A. 4. Turkish Textile Plants' Inventory Data (EIA Reports)

Dyeing Process Inputs and Outputs (per 1 ton of fabric dyed)							
Category	Unit	Bilhan Tekstil	Savcan Tekstil San. ve Tic. A.Ş.	Net Tekstil	Gülcehal Tekstil	Yedikardeş Tekstil	Broş Tekstil
Dyeing Method	-	Jet Dyeing (Batch)	Jet Dyeing (Batch)	Jet Dyeing (Batch)	Jet Dyeing (Batch)	Jet Dyeing (Batch)	HT Dyeing (Batch)
Liquor ratio	-	1:10	1:10	1:6	-	-	1:6
Water	kg	99090.9	18892.6	60000.0	24111.1	46587.3	48000.0
Wastewater	kg	99090.9	18892.6	60000.0	24111.1	46587.3	48000.0
Reactive dye	kg	30.0	30.0	30.0	30.0	30.0	50.0
Sodium carbonate (soda)	kg	20.0	20.0	200.0	20.0	20.0	300.0
Sodium bicarbonate	kg						
Urea	kg	30.0	30.0		30.0	30.0	
NaOH	kg	10.0	10.0	30.0	10.0	10.0	
Salt	kg	200.0	200.0	1400.0	150.0	150.0	1100.0
Soap	kg			10.0			30.0
Detergent	kg	20.0			20.0	20.0	

Table A. 5. Steam Production Details Defined in Ecoinvent Database

Dataset definition	This dataset represents the production of 1 kg of steam used for heating in the chemical industry. The heat is produced with the average fuel mix used in the European chemical industry. This dataset represents only the unit conversion of steam in MJ to steam in kg, with an assumed energy content of 2.75 MJ/kg. The energy losses and water use are taken into account in the upstream process, which is based on data from Eurostat (2017). Even though the reference product is expressed in kg, the exchange does not have any mass, as all inputs and emissions are already included in its supply chain. It can be used as an exchange for a massless carrier of energy.
Production volume	327023493120 kg
Included activities start	The activity starts with the input of heat required to produce 1 kg of steam.
Included activities end	The activity ends with the production of 1 kg of steam. The energy and water losses are taken into account in the upstream process. Assuming a closed loop of water with the losses already taken into account, no further water flows are included in this process.
Geography	The inventory is modelled for Europe
Technology	Most often this type of boiler is built specifically according to the power and specifications required. The range of powers starts at 15 or 20 MWt, up to several hundreds of MWth, and even beyond. They are currently most often equipped with low NOx type burners, that use natural gas staging technique or/and internal flue gas recirculation. These boilers produce steam and high pressure hot water, and their power ranges from 3 to 20 MWt. They are currently most often equipped with low NOx type burners, which use primary measures for the reduction of NOx emissions (natural gas staging technique or/and flue gas recirculation).
Steam Temperature	130 °C

Table A. 6. Mass Balance for K. Acid Production

Inputs	
Material	MT/MT
B-Naphthol	1.33
Sulfuric Acid (98%)	2.44
Oleum (65%)	2.68
Water	4.01
Sodium Sulphate (98%)	1.50
Ammonia (24%)	2.83
Sodium Bicarbonate (SBC)	0.92
Outputs	
Sodium Bisulphate (SBS)	2.27
CO ₂	0.10
Spent Sulfuric Acid (40-45%)	2.26
NH ₄ OH	1.78

Table A. 7. Mass Balance for Meta Ureido Aniline (MUA) Production

Inputs	
Material	MT/MT
B-Naphthol	1.33
Sulfuric Acid (98%)	2.44
Oleum (65%)	2.68
Water	4.01
Sodium Sulphate (98%)	1.50
Ammonia (24%)	2.83
Sodium Bicarbonate (SBC)	0.92
Outputs	
Wastewater	3.85

Table A. 8. Commonly Found Chlorobenzene Species in the Textile Dyeing Wastewater (Y. Yuan et al., 2020)

Chlorobenzene Levels	Unit	Value
Trichlorobenzenes (TCB)	ug/L	0.26
1,2,3,5 Tetrachlorobenzenes (TECB)	ug/L	0.25
Pentachlorobenzenes (PCB)	ug/L	0.08
Hexachlorobenzenes (HCB)	ug/L	0.07



B. Assumptions Made in LCA Study

1. In the reactive dyeing recipes, the amount of salt, dye, and other auxiliary chemicals are defined per 1 kg of textile material to be dyed. Therefore, regardless of the differences in techniques, the amount of all these chemicals is the same for jet, jigger and pad-steam dyeing methods.
2. In all dyeing scenarios, wastewater production equals to the water consumption.
3. The reactive dye fixation ratio is 40%.
4. 10% of COD is remained in the warm rinsing bath (the last stage), while the other 90% is in the wastewater from the dye bath, hot rinsing, and soap washing stages (first three stages).
5. 10% of TOC is remained in the warm rinsing bath, while the other 90% is in the wastewater from the dye bath, hot rinsing, and soap washing stages.
6. All the salt content remained in the wastewater from the dye bath, hot rinsing, and soap washing stages.
7. All the AOX (TCB, TECB, PCB, HCB) content remained in the wastewater from the dye bath, hot rinsing, and soap washing stages.
8. All the heavy metal content remained in the wastewater from the dye bath, hot rinsing, and soap washing stages.
9. All the DEHP content remained in the wastewater from the dye bath, hot rinsing, and soap washing stages.
10. All the P content remained in the wastewater from the dye bath, hot rinsing, and soap washing stages.
11. All the Ammonia content remained in the wastewater from the dye bath, hot rinsing, and soap washing stages.
12. Reuse of permeate does not change the amount of steam consumption and the related emission levels.
13. For chemical inputs that are not present in the SimaPro database and could not be introduced to the software due to the inaccessibility of production data, chemicals available in the databases with similar properties were entered.

- i. Beta-naphthol is defined as Alpha-naphthol
- ii. Oleum is defined as Sulfur Trioxide
- iii. $\text{Na}_6\text{P}_6\text{O}_{18}$ (Calgon) is defined by its two primary constituents, Phosphoric Acid and Sodium Hydroxide.



C. Details of Membrane Treatment Scenarios

C.1. Jet Dyeing Membrane Treatment Scenarios

C.1.1. Scenario 1.1 (Direct UF)

Table C. 1 presents the UF system overview with the main operational parameters and amounts of chemicals used for the operation.

Table C. 1. Scenario 1.1 - UF System Overview

Parameters	Value
Number of modules	11
Operating Flux	73 LMH
System Recovery	93.4 %
Feed pump pressure	3.1 bar
Trans membrane pressure (TMP)	0.25 bar
Feed flow rate	36 m ³ /h
Product flow rate	33.4 m ³ /h
Waste flow rate	2.4 m ³ /h
Energy consumption	44.82 kWh/d
Chemical consumption for cleaning:	
HCl (32%)	0.90 kg/d
NaOCl (12%)	22.24 kg/d
Citric Acid (100%)	0.67 kg/d
NaOH (50%)	9.34 kg/d

In Table C. 2, the feed water parameters and UF product water quality results are given.

Table C. 2. Scenario 1.1 - Feed Water and Product Water Details

Parameters	Feed	Product Water
Flow rate (m ³ /h)	36	33.4
Temperature (°C)	35	35
Turbidity (NTU)	100	≤ 0.1
Total Suspended Solids (TSS) (mg/L)	100	-
Organics (TOC) (mg/L)	100	30
Total Dissolved Solids (TDS) (mg/L)	11099	11099
Na ⁺ (mg/L)	4364	4364
Cl ⁻ (mg/L)	6736	6736
NaCl Amount (kg)	400	370.7
pH	8.0	8.0

Product water quality analysis showed that the UF module has a 70% TOC and 7.3% salt removal, which is the desired result for the reuse of brackish permeate.

C.1.2. Scenario 1.2 (Direct NF)

Table C. 3 presents the NF system flow diagram descriptions.

Table C. 3. Scenario 1.2. - NF System Flow Diagram Description

Description	Flow rate (m ³ /h)	TDS (mg/L)	Pressure (bar)
Raw feed to NF system	36.0	11,099	0.0
Net Feed to Pass 1	39.4	11,861	7.2
Concentrate Recycle from Pass 1 to Pass 1	3.45	11,861	5.3
Total Concentrate from Pass 1	9.86	19,768	5.3
Net Concentrate from NF System	6.41	19,768	5.3
Net Product from NF System	29.6	9,219	0.0

In Table C. 4, the NF system overview with the main operational parameters and amounts of chemicals used for the operation are summarized.

Table C. 4. Scenario 1.2 - NF System Overview

Parameters	Value
Number of elements	54
Total active area	2007 m ²
Feed flow per pass	39.4 m ³ /h
Feed TDS	11,861 mg/L
Feed pressure	7.2 bar
Permeate Flow per Pass	29.6 m ³ /h
Pass average flux	14.7 LMH
Permeate TDS	9,219 mg/L
Pass Recovery	75.1 %
System Recovery	82.2 %
Concentrate flow rate	6.41 m ³ /h
Energy consumption	236.6 kWh/d
Chemical consumption:	
Na ₆ P ₆ O ₁₈ (100%)	2.59 kg/d
HCl (32%)	0.60 kg/d

In Table C. 5, the feed water parameters and NF product water quality results are given.

Table C. 5. Scenario 1.2 - Feed Water and NF Solute Concentrations

Parameters	Raw Feed	Feed After Recycle	Concentrate	Permeate
pH	8.0	6.0	5.3	6.7
Na ⁺ (mg/L)	4,366	4,665	7,776	3,627
Cl ⁻ (mg/L)	6,733	7,195	11,992	5,593
TDS (mg/L)	11,099	11,860	19,768	9,219
NaCl Amount (kg)	400	-	127	273
Conductivity (μS/cm)	19,278	20,490	32,697	16,245
TOC (mg/L)	100	-	-	20

Product water quality analysis showed that the NF module has 80% TOC and 31.8% salt removal.

C.1.3. Scenario 1.3 (Combined UF+NF)

UF Pretreatment Design

Table C. 6 presents the UF pretreatment system overview with the main operational parameters and amounts of chemicals used for the operation. Compared to Scenario 1.1, the chemical consumption for the cleaning is significantly lower due to the membrane characteristics.

Table C. 6. Scenario 1.3 - UF Pretreatment System Overview

Parameters	Value
Number of modules	9
Operating Flux	93 LMH
System Recovery	93.6 %
Feed pump pressure	3.5 bar
Transmembrane pressure (TMP)	0.32 bar
Feed flow rate	36 m ³ /h
Product flow rate	33.5 m ³ /h
Waste flow rate	2.4 m ³ /h
Energy consumption	47.31 kWh/d
Chemical consumption for cleaning:	
HCl (32%)	0.50 kg/d
NaOCl (12%)	11.52 kg/d
Citric Acid (100%)	0.41 kg/d
NaOH (50%)	3.95 kg/d

In Table C. 7, the feed water parameters and UF product water quality results are given.

Table C. 7. Scenario 1.3 - Feed Water and Product Water Details

Parameters	Feed	Product Water
Flow rate (m ³ /h)	36	33.5
Temperature (°C)	35	35
Turbidity (NTU)	100	≤ 0.1
Total Suspended Solids (TSS) (mg/L)	100	-
Organics (TOC) (mg/L)	100	30
Total Dissolved Solids (TDS) (mg/L)	11099	11099
Na ⁺ (mg/L)	4364	4364
Cl ⁻ (mg/L)	6736	6736
NaCl Amount (kg)	400	371.8
pH	8.0	8.0

The permeate water quality results of SFP-2860XP UF pretreatment are quite similar to that of IP-51XP. However, with 7% salt removal, there is a slight decrease in the salt removal ratio in this scenario.

NF Treatment Design

Table C. 8 presents the NF system flow diagram descriptions.

Table C. 8. Scenario 1.3 - NF System Flow Diagram Description

Description	Flow rate (m ³ /h)	TDS (mg/L)	Pressure (bar)
Raw feed to NF system	33.5	11,099	0.0
Net Feed to Pass 1	36.6	11,968	7.9
Concentrate Recycle from Pass 1 to Pass 1	3.07	21,392	6.1
Total Concentrate from Pass 1	8.78	21,392	6.1
Net Concentrate from NF System	5.71	21,392	6.1
Net Product from NF System	27.8	8,985	0.0
Net NF Product after UF use	27.8	8,985	0.0
NF Permeate used for UF	0.07	8,985	0.0

In Table C. 9, the NF system overview with the main operational parameters and amounts of chemicals used for the operation are summarized.

Table C. 9. Scenario 1.3 - NF System Overview

Parameters	Value
Number of elements	54
Total active area	2007 m ²
Feed flow per pass	36.6 m ³ /h
Feed TDS	11,967 mg/L
Feed pressure	7.9 bar
Permeate Flow per Pass	27.8 m ³ /h
Pass average flux	13.9 LMH
Permeate TDS	8,985 mg/L
Pass Recovery	76 %
System Recovery	82.7 %
Concentrate flow rate	5.71 m ³ /h
Energy consumption	242.9 kWh/d
Chemical consumption:	
Na ₆ P ₆ O ₁₈ (100%)	2.41 kg/d
HCl (32%)	0.4 kg/d

In Table C. 10, the feed water parameters and NF product water quality results are given. It should be noted that the permeate from UF is the feed of the NF stage.

Table C. 10. Scenario 1.3 - Feed Water and NF Solute Concentrations

Parameters	Raw Feed	Feed After Recycle	Concentrate	Permeate
pH	8.0	6.0	5.3	6.7
Na ⁺ (mg/L)	4,366	4,707	8,415	3,534
Cl ⁻ (mg/L)	6,733	7,259	12,977	5,450
TDS (mg/L)	11,099	11,966	21,392	8,985
NaCl Amount (kg)	372	-	122	250
Conductivity (μS/cm)	19,277	20,658	35,140	15,862

Table C. 10 (cont'd)

Parameters	Raw Feed	Feed After Recycle	Concentrate	Permeate
TOC (mg/L)	30	-	-	6

When product water quality is analyzed, it can be seen that salt is removed by 32.8% with NF application, and the remaining TOC concentration is very low, as expected.

In Table C. 11, the overall UF+NF combined system results are summarized and presented.

Table C. 11. Scenario 1.3 - UF+NF Overall System Summary

	Parameters	UF	NF
Feed	Flow rate (m ³ /h)	36	33.5
	TOC (mg/L)	100	30
	TDS (mg/L)	11,099	11,099
	NaCl Amount (kg)	400	372
Product	Flow rate (m ³ /h)	33.5	27.8
	TOC (mg/L)	30	6
	TDS (mg/L)	11,099	8,985
	NaCl Amount (kg)	372	250
	Recovery	93.6 %	82.7 %
Overall System Recovery		77.1 %	

Product water quality analysis showed that the overall system is capable of removing TOC with a 94% efficiency. In addition, overall NaCl removal is observed to be 37.6%, which is a desired level of removal for the reuse of brackish permeate.

C.2. Jigger Dyeing Membrane Treatment Scenarios

C.2.1. Scenario 2.1 (Direct UF)

Table C. 12 presents the UF system overview with the main operational parameters and amounts of chemicals used for the operation.

Table C. 12. Scenario 2.1 - UF System Overview

Parameters	Value
Number of modules	8
Operating Flux	67 LMH
System Recovery	92.8 %
Feed pump pressure	3.1 bar
Transmembrane pressure (TMP)	0.23 bar
Feed flow rate	24 m ³ /h
Product flow rate	22.2 m ³ /h
Waste flow rate	1.7 m ³ /h
Energy consumption	30.33 kWh/d
Chemical consumption for cleaning:	
HCl (32%)	0.70 kg/d
NaOCl (12%)	16.18 kg/d
Citric Acid (100%)	0.49 kg/d
NaOH (50%)	6.98 kg/d

In Table C. 13 the feed water parameters and UF product water quality results are given.

Table C. 13. Scenario 2.1 - Feed Water and Product Water Details

Parameters	Feed	Product Water
Flow rate (m ³ /h)	24	22.2
Temperature (°C)	35	35
Turbidity (NTU)	100	≤ 0.1
Total Suspended Solids (TSS) (mg/L)	100	-
Organics (TOC) (mg/L)	100	30
Total Dissolved Solids (TDS) (mg/L)	16699	16699
Na ⁺ (mg/L)	6566	6566
Cl ⁻ (mg/L)	10134	10134
NaCl Amount (kg)	400	370.7
pH	8.0	8.0

Product water quality analysis showed that the UF module has a 70% TOC and 7.3% salt removal, which is the desired result for the reuse of brackish permeate.

C.2.2. Scenario 2.2 (Direct NF)

Table C. 14 presents the NF system flow diagram descriptions.

Table C. 14. Scenario 2.2 - NF System Flow Diagram Description

Description	Flow rate (m ³ /h)	TDS (mg/L)	Pressure (bar)
Raw feed to NF system	24.0	16,699	0.0
Net Feed to Pass 1	26.7	17,622	7.9
Concentrate Recycle from Pass 1 to Pass 1	2.71	25,746	5.1
Total Concentrate from Pass 1	7.74	25,746	5.1
Net Concentrate from NF System	5.03	25,746	5.1
Net Product from NF System	19.0	13,968	0.0

In Table C. 15, the NF system overview with the main operational parameters and amounts of chemicals used for the operation are summarized.

Table C. 15. Scenario 2.2 - NF System Overview

Parameters	Value
Number of elements	48
Total active area	1784 m ²
Feed flow per pass	26.7 m ³ /h
Feed TDS	17,622 mg/L
Feed pressure	7.9 bar
Permeate Flow per Pass	19.0 m ³ /h
Pass average flux	10.6 LMH
Permeate TDS	14,293 mg/L
Pass Recovery	71.2 %
System Recovery	79.0 %
Concentrate flow rate	5.03 m ³ /h
Energy consumption	175.1 kWh/d
Chemical consumption:	

Table C. 15 (cont'd)

Parameters	Value
Na ₆ P ₆ O ₁₈ (100%)	1.73 kg/d
HCl (32%)	0.40 kg/d

In Table C. 16, the feed water parameters and NF product water quality results are given.

Table C. 16. Scenario 2.2 - Feed Water and NF Solute Concentrations

Parameters	Raw Feed	Feed After Recycle	Concentrate	Permeate
pH	8.0	5.9	5.3	6.6
Na ⁺ (mg/L)	6,569	6,932	10,128	5,623
Cl ⁻ (mg/L)	10,130	10,689	15,618	8,671
TDS (mg/L)	16,699	17,621	25,746	14,293
NaCl Amount (kg)	400	-	128.4	271.6
Conductivity (μS/cm)	28,034	29,443	41,558	24,316
TOC (mg/L)	100	-	-	20

Product water quality analysis showed that the NF module has 80% TOC and 32.1% salt removal efficiency.

C.2.3. Scenario 2.3 (Combined UF+NF)

UF Pretreatment Design

Table C. 17 presents the UF pretreatment system overview with the main operational parameters and amounts of chemicals used for the operation. Compared to Scenario 2.1, the chemical consumption for the cleaning is significantly lower.

Table C. 17. Scenario 2.3 - UF Pretreatment System Overview

Parameters	Value
Number of modules	6
Operating Flux	93 LMH
System Recovery	93.6 %

Table C. 17 (cont'd)

Parameters	Value
Feed pump pressure	3.5 bar
Transmembrane pressure (TMP)	0.32 bar
Feed flow rate	24 m ³ /h
Product flow rate	22.4 m ³ /h
Waste flow rate	1.6 m ³ /h
Energy consumption	32.34 kWh/d
Chemical consumption for cleaning:	
HCl (32%)	0.30 kg/d
NaOCl (12%)	7.67 kg/d
Citric Acid (100%)	0.28 kg/d
NaOH (50%)	2.71 kg/d

Table C. 18 shows the feed water parameters and UF product water quality results.

Table C. 18. Scenario 2.3 - Feed Water and Product Water Details

Parameters	Feed	Product Water
Flow rate (m ³ /h)	24	22.4
Temperature (°C)	35	35
Turbidity (NTU)	100	≤ 0.1
Total Suspended Solids (TSS) (mg/L)	100	-
Organics (TOC) (mg/L)	100	30
Total Dissolved Solids (TDS) (mg/L)	16699	16699
Na ⁺ (mg/L)	6566	6566
Cl ⁻ (mg/L)	10134	10134
NaCl Amount (kg)	400	374.06
pH	8.0	8.0

In this scenario, with a 6.5% salt removal, a decrease in salt removal percentage was observed compared to Scenario 3.1, as was observed in jet dyeing scenarios.

NF Treatment Design

Table C. 19 presents the NF system flow diagram descriptions.

Table C. 19. Scenario 2.3 - NF System Flow Diagram Description

Description	Flow rate (m³/h)	TDS (mg/L)	Pressure (bar)
Raw feed to NF system	22.4	16,699	0.0
Net Feed to Pass 1	25.3	17,748	8.3
Concentrate Recycle from Pass 1 to Pass 1	2.92	25,743	5.4
Total Concentrate from Pass 1	8.34	25,742	5.4
Net Concentrate from NF System	5.42	25,742	5.4
Net Product from NF System	16.9	13,801	0.0
Net NF Product after UF use	16.9	13,800	0.0
NF Permeate used for UF	0.05	13,800	0.0

Table C. 20 summarizes the NF system overview with the main operational parameters and amounts of chemicals used for the operation.

Table C. 20. Scenario 2.3 - NF System Overview

Parameters	Value
Number of elements	48
Total active area	1784 m ²
Feed flow per pass	25.3 m ³ /h
Feed TDS	17,748 mg/L
Feed pressure	8.3 bar
Permeate Flow per Pass	16.9 m ³ /h
Pass average flux	9.5 LMH
Permeate TDS	13,801 mg/L
Pass Recovery	66.8 %
System Recovery	75.5 %
Concentrate flow rate	5.42 m ³ /h
Energy consumption	175 kWh/d

Table C. 20 (cont'd)

Parameters	Value
Chemical consumption:	
Na ₆ P ₆ O ₁₈ (100%)	1.61 kg/d
HCl (32%)	0.3 kg/d

In Table C. 21, the feed water parameters and NF product water quality results are given.

Table C. 21. Scenario 2.3 - Feed Water and NF Solute Concentrations

Parameters	Raw Feed	Feed After Recycle	Concentrate	Permeate
pH	8.0	5.9	5.4	6.7
Na ⁺ (mg/L)	6,569	6,981	10,126	5,429
Cl ⁻ (mg/L)	10,130	10,766	15,616	8,372
TDS (mg/L)	16,699	17,747	25,742	13,801
NaCl Amount (kg)	374.06	-	140.82	233.24
Conductivity (μS/cm)	28,034	29,636	41,553	23,548
TOC (mg/L)	30	-	-	6

When product water quality is analyzed, it can be seen that salt is removed by 37.6% with NF application, and the remaining TOC concentration is very low, as expected.

In Table C. 22, the overall UF+NF combined system results are summarized and presented.

Table C. 22. Scenario 2.3 - UF+NF Overall System Summary

	Parameters	UF	NF
Feed	Flow rate (m ³ /h)	24	22.4
	TOC (mg/L)	100	30
	TDS (mg/L)	16,699	16,699
	NaCl Amount (kg)	400	374.06
Product	Flow rate (m ³ /h)	22.4	16.9
	TOC (mg/L)	30	6
	TDS (mg/L)	16,699	13,801

Table C. 22 (cont'd)

Parameters	UF	NF
NaCl Amount (kg)	374.06	233.24
Recovery	93.6 %	75.5 %
Overall System Recovery	70.4 %	

When product water quality is analyzed, it can be seen that the overall system is capable of removing TOC with a 94% efficiency. In addition, overall NaCl removal is observed to be 41.7%. A significant reduction in permeate recovery efficiency was observed compared to the jet dyeing scenarios, which was attributed to the 34% higher NaCl concentration in the feed water.

C.3. Pad Dyeing Membrane Treatment Scenarios

C.3.1. Scenario 3.1 (Direct UF)

Table C. 23 presents the UF system overview with the main operational parameters and amounts of chemicals used for the operation.

Table C. 23. Scenario 3.1 - UF System Overview

Parameters	Value
Number of modules	6
Operating Flux	67 LMH
System Recovery	92.8 %
Feed pump pressure	3.1 bar
Transmembrane pressure (TMP)	0.23 bar
Feed flow rate	18 m ³ /h
Product flow rate	16.6 m ³ /h
Waste flow rate	1.3 m ³ /h
Energy consumption	23.34 kWh/d
Chemical consumption for cleaning:	
HCl (32%)	0.50 kg/d

Table C. 23 (cont'd)

Parameters	Value
NaOCl (12%)	12.12 kg/d
Citric Acid (100%)	0.36 kg/d
NaOH (50%)	5.27 kg/d

In Table C. 24, the feed water parameters and UF product water quality results are given.

Table C. 24. Scenario 3.1 - Feed Water and Product Water Details

Parameters	Feed	Product Water
Flow rate (m ³ /h)	18	16.6
Temperature (°C)	35	35
Turbidity (NTU)	100	≤ 0.1
Total Suspended Solids (TSS) (mg/L)	100	-
Organics (TOC) (mg/L)	100	30
Total Dissolved Solids (TDS) (mg/L)	22,198	22,198
Na ⁺ (mg/L)	8,732	8,732
Cl ⁻ (mg/L)	13,466	13,466
NaCl Amount (kg)	400	368.5
pH	8.0	8.0

Product water quality analysis showed that the UF module has a 70% TOC removal and 8.6% salt removal, which is the desired result for the reuse of brackish permeate.

C.3.2. Scenario 3.2 (Direct NF)

Table C. 25 presents the NF system flow diagram descriptions.

Table C. 25. Scenario 3.2 - NF System Flow Diagram Description

Description	Flow rate (m ³ /h)	TDS (mg/L)	Pressure (bar)
Raw feed to NF system	18.0	22,198	0.0
Net Feed to Pass 1	20.5	23,256	8.1
Concentrate Recycle from Pass 1 to Pass 1	2.51	30,781	5.4

Table C. 25 (cont'd)

Description	Flow rate (m³/h)	TDS (mg/L)	Pressure (bar)
Total Concentrate from Pass 1	7.18	30,781	5.4
Net Concentrate from NF System	4.67	30,781	5.4
Net Product from NF System	13.3	19,191	0.0

In Table C. 26, the NF system overview with the main operational parameters and amounts of chemicals used for the operation are summarized.

Table C. 26. Scenario 3.2 - NF System Overview

Parameters	Value
Number of elements	42
Total active area	1561 m ²
Feed flow per pass	20.5 m ³ /h
Feed TDS	23,256 mg/L
Feed pressure	8.1 bar
Permeate Flow per Pass	13.3 m ³ /h
Pass average flux	8.5 LMH
Permeate TDS	19,191 mg/L
Pass Recovery	64.9 %
System Recovery	74.1 %
Concentrate flow rate	4.67 m ³ /h
Energy consumption	138.6 kWh/d
Chemical consumption:	
Na ₆ P ₆ O ₁₈ (100%)	1.30 kg/d
HCl (32%)	0.30 kg/d

In Table C. 27, the feed water parameters and NF product water quality results are given.

Table C. 27. Scenario 3.2 - Feed Water and NF Solute Concentrations

Parameters	Raw Feed	Feed After Recycle	Concentrate	Permeate
pH	8.0	5.9	5.4	6.6
Na ⁺ (mg/L)	8,732	9,148	12,109	7,549
Cl ⁻ (mg/L)	13,466	14,107	18,673	11,642
TDS (mg/L)	22,198	23,255	30,781	19,191
NaCl Amount (kg)	400	-	145	255
Conductivity (μS/cm)	36,330	37,896	48,842	31,824
TOC (mg/L)	100	-	-	20

Product water quality analysis showed that the NF module has 80% TOC and 36.2% salt removal efficiency.

C.3.3. Scenario 3.3 (Combined UF+NF)

UF Pretreatment Design

Table C. 28 presents the UF pretreatment system overview with the main operational parameters and amounts of chemicals used for the operation.

Table C. 28. Scenario 3.3 - UF Pretreatment System Overview

Parameters	Value
Number of modules	5
Operating Flux	84 LMH
System Recovery	92.9 %
Feed pump pressure	3.5 bar
Transmembrane pressure (TMP)	0.29 bar
Feed flow rate	18 m ³ /h
Product flow rate	16.6 m ³ /h

Table C. 28 (cont'd)

Parameters	Value
Waste flow rate	1.3 m ³ /h
Energy consumption	24.44 kWh/d
Chemical consumption for cleaning:	
HCl (32%)	0.30 kg/d
NaOCl (12%)	6.39 kg/d
Citric Acid (100%)	0.23 kg/d
NaOH (50%)	2.29 kg/d

In Table C. 29, the feed water parameters and UF product water quality results are given.

Table C. 29. Scenario 3.3 - Feed Water and Product Water Details

Parameters	Feed	Product Water
Flow rate (m ³ /h)	18	16.6
Temperature (°C)	35	35
Turbidity (NTU)	100	≤ 0.1
Total Suspended Solids (TSS) (mg/L)	100	-
Organics (TOC) (mg/L)	100	30
Total Dissolved Solids (TDS) (mg/L)	22,198	22,198
Na ⁺ (mg/L)	8,732	8,732
Cl ⁻ (mg/L)	13,466	13,466
NaCl Amount (kg)	400	368.5
pH	8.0	8.0

In this scenario, with a 7.9% salt removal, a decrease in salt removal was observed compared to Scenario 3.1, which is a parallel result with jet and jigger dyeing scenarios.

NF Treatment Design

Table C. 30 presents the NF system flow diagram descriptions.

Table C. 30. Scenario 3.3 - NF System Flow Diagram Description

Description	Flow rate (m³/h)	TDS (mg/L)	Pressure (bar)
Raw feed to NF system	16.6	22,198	0.0
Net Feed to Pass 1	19.0	23,399	8.8
Concentrate Recycle from Pass 1 to Pass 1	2.40	31,673	6.1
Total Concentrate from Pass 1	6.85	31,673	6.1
Net Concentrate from NF System	4.45	31,673	6.1
Net Product from NF System	12.2	18,731	0.0
Net NF Product after UF use	12.1	18,730	0.0
NF Permeate used for UF	0.04	18,730	0.0

In Table C. 31, the NF system overview with the main operational parameters and amounts of chemicals used for the operation are summarized.

Table C. 31. Scenario 3.3 - NF System Overview

Parameters	Value
Number of elements	42
Total active area	1561 m ²
Feed flow per pass	19.0 m ³ /h
Feed TDS	23,299 mg/L
Feed pressure	8.8 bar
Permeate Flow per Pass	12.2 m ³ /h
Pass average flux	7.8 LMH
Permeate TDS	18,731 mg/L
Pass Recovery	64.2 %
System Recovery	73.0 %
Concentrate flow rate	4.45 m ³ /h
Energy consumption	139.6 kWh/d

Table C. 31 (cont'd)

Parameters	Value
Chemical consumption:	
Na ₆ P ₆ O ₁₈ (100%)	1.20 kg/d
HCl (32%)	0.20 kg/d

In Table C. 32, the feed water parameters and NF product water quality results are given.

Table C. 32. Scenario 3.3 - Feed Water and NF Solute Concentrations

Parameters	Raw Feed	Feed After Recycle	Concentrate	Permeate
pH	8.0	5.9	5.4	6.7
Na ⁺ (mg/L)	8,732	9,204	12,459	7,268
Cl ⁻ (mg/L)	13,466	14,194	19,213	11,362
TDS (mg/L)	22,198	23,398	31,672	18,731
NaCl Amount (kg)	368.50	-	140	228.50
Conductivity (μS/cm)	36,329	38,107	50,117	31,129
TOC (mg/L)	30	-	-	6

Table C. 32 shows that salt is removed by 38% with NF application, which is a slightly higher salt rejection rate compared to the direct NF scenario (Scenario 3.2).

In Table C. 33, the overall UF+NF combined system results are summarized and presented.

Table C. 33. Scenario 3.3 - UF+NF Overall System Summary

	Parameters	UF	NF
Feed	Flow rate (m ³ /h)	18	16.6
	TOC (mg/L)	100	30
	TDS (mg/L)	22,198	22,198
	NaCl Amount (kg)	400	368.5
Product	Flow rate (m ³ /h)	16.6	12.2
	TOC (mg/L)	30	6

Table C. 33 (cont'd)

Parameters	UF	NF
TDS (mg/L)	22,198	18,731
NaCl Amount (kg)	368.50	228.50
Recovery	92.9 %	73.0 %
Overall System Recovery	67.5 %	

When product water quality is analyzed, it can be seen that the overall system is capable of removing TOC with a 94% efficiency. In addition, overall NaCl removal is observed to be 42.9%. A significant reduction in permeate recovery efficiency was observed in pad dyeing membrane treatment scenarios compared to the jet and jigger dyeing scenarios. This result was associated with the salt concentration in pad dyeing wastewater being 50% higher than jet dyeing and 25% higher than jigger dyeing wastewater salt concentrations.

C.4. Water and Salt Recovery Performances of Membrane Treatment Scenarios

Table C. 34. Water and Salt Recovery Performances of Membrane Treatment Scenarios

Scenarios	Jet Dyeing		Jigger Dyeing		Pad-Steam Dyeing	
	NaCl Recovery (%)	Water Recovery (%)	NaCl Recovery (%)	Water Recovery (%)	NaCl Recovery (%)	Water Recovery (%)
UF-only Treatment	92.7	69.6	92.7	69.4	92.1	69.2
UF-only Treatment	68.2	61.7	67.9	59.4	63.8	55.4
UF+NF Treatment	62.4	57.9	58.3	52.8	57.1	50.8

C.5. Mass Balance Flow Charts of Membrane Treatment Scenarios

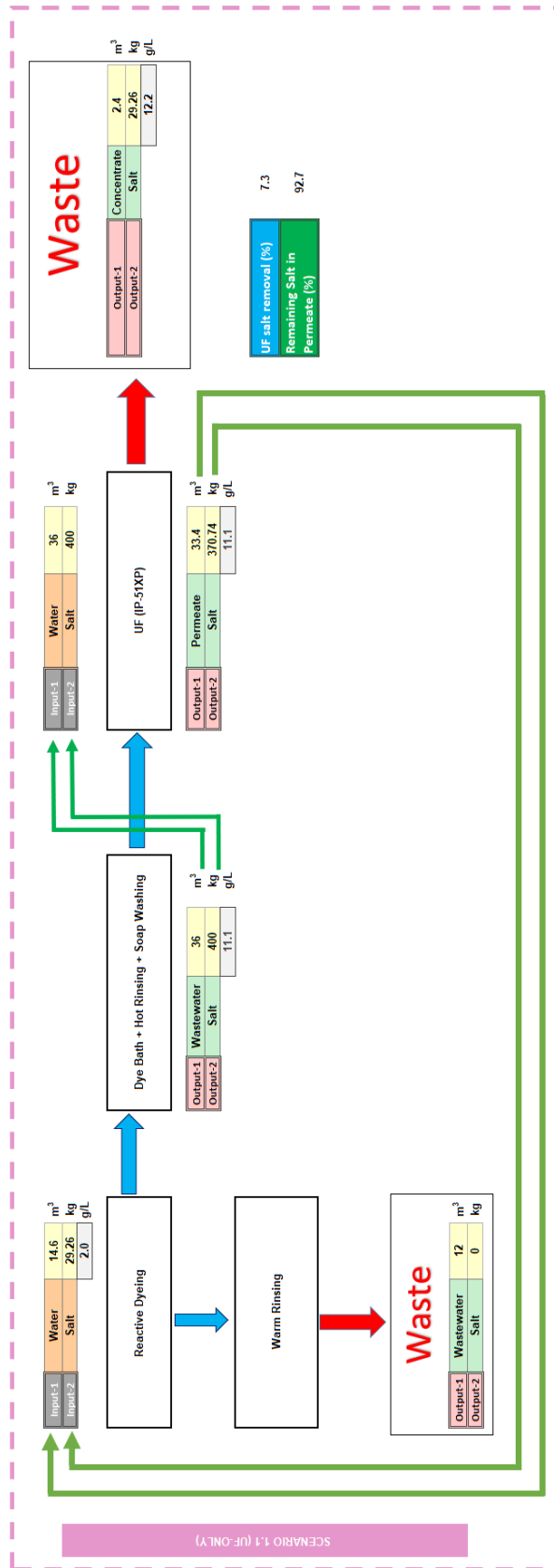


Figure C. 1. Scenario 1.1 Mass Balance Flow Chart

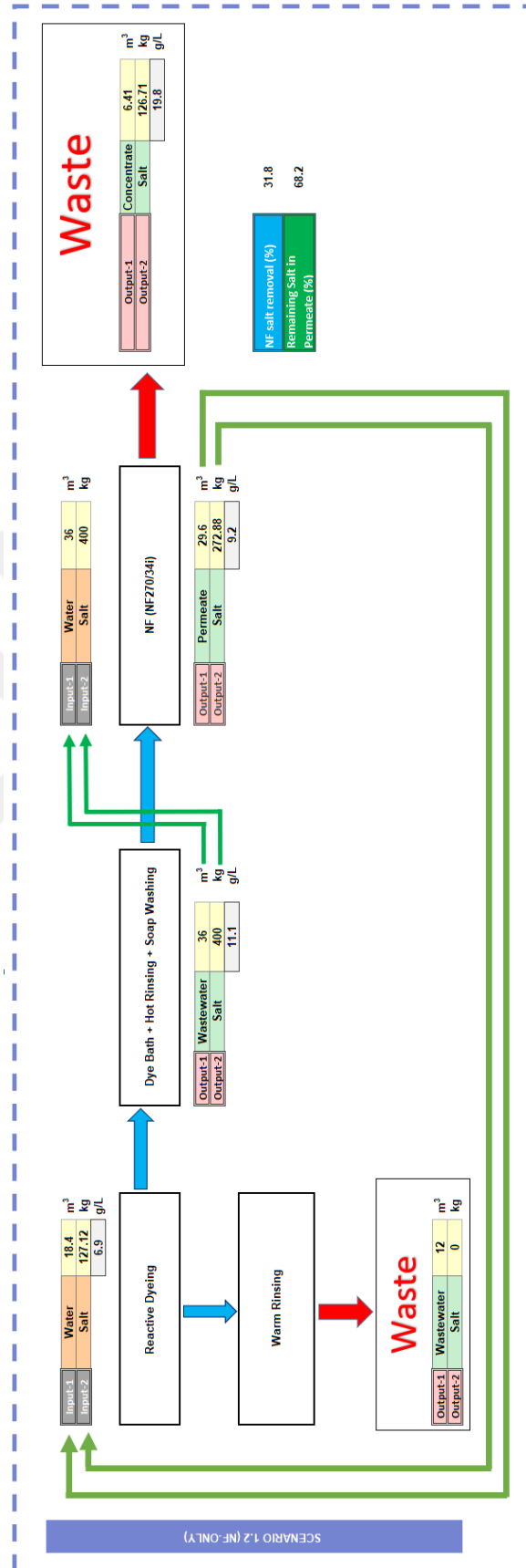


Figure C. 2. Scenario 1.2 Mass Balance Flow Chart

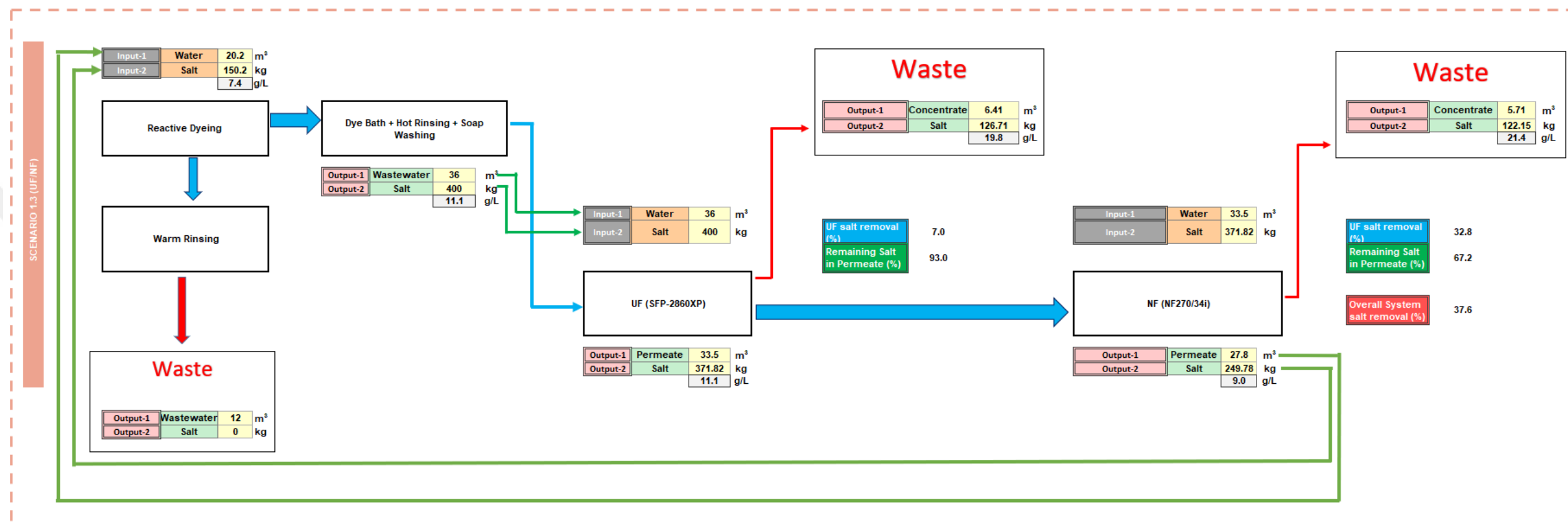


Figure C. 3. Scenario 1.3 Mass Balance Flow Chart

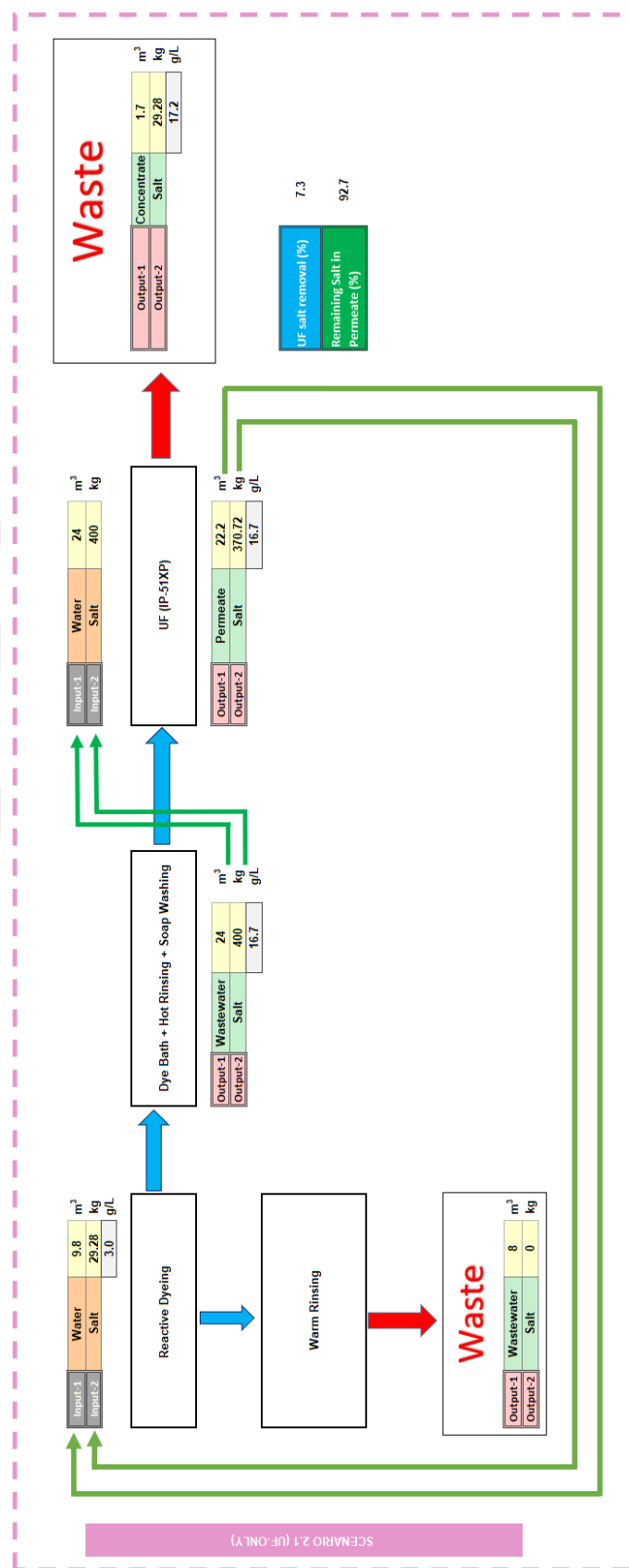


Figure C. 4. Scenario 2.1 Mass Balance Flow Chart

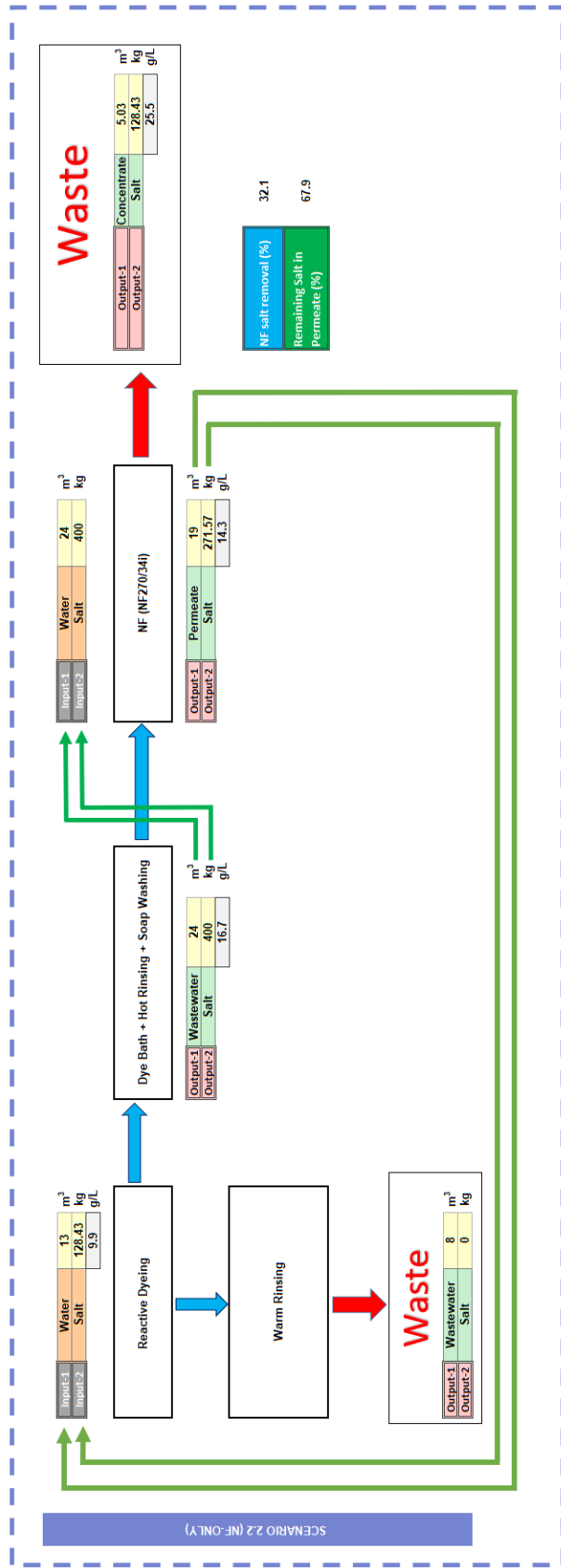


Figure C. 5. Scenario 2.2 Mass Balance Flow Chart

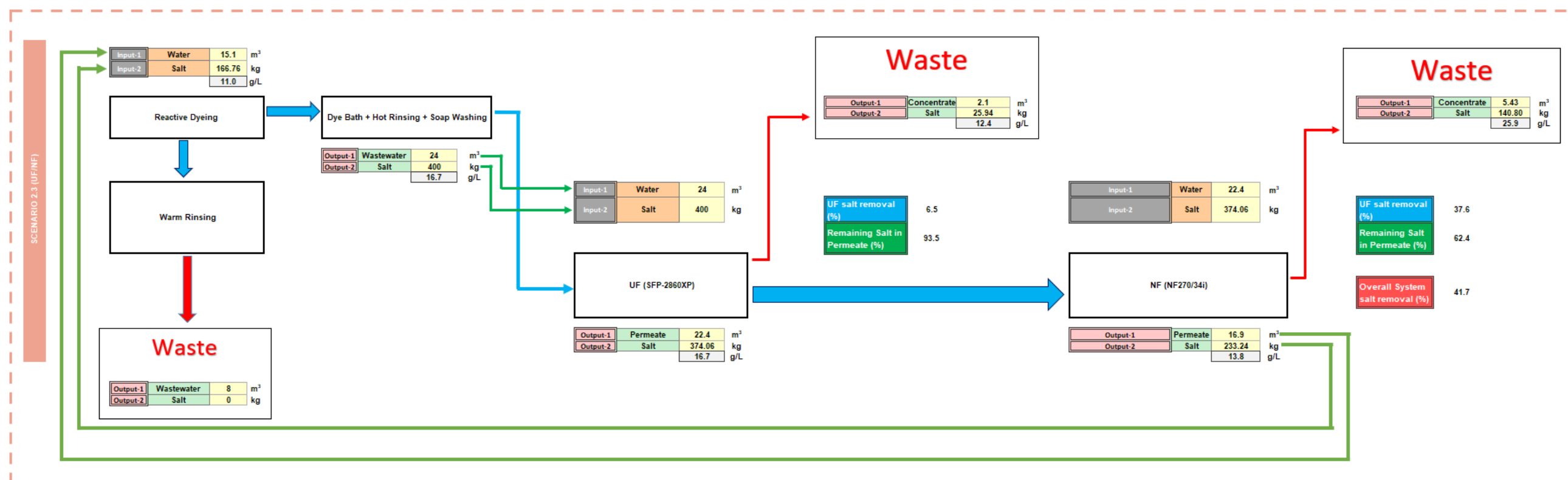


Figure C. 6. Scenario 2.3 Mass Balance Flow Chart

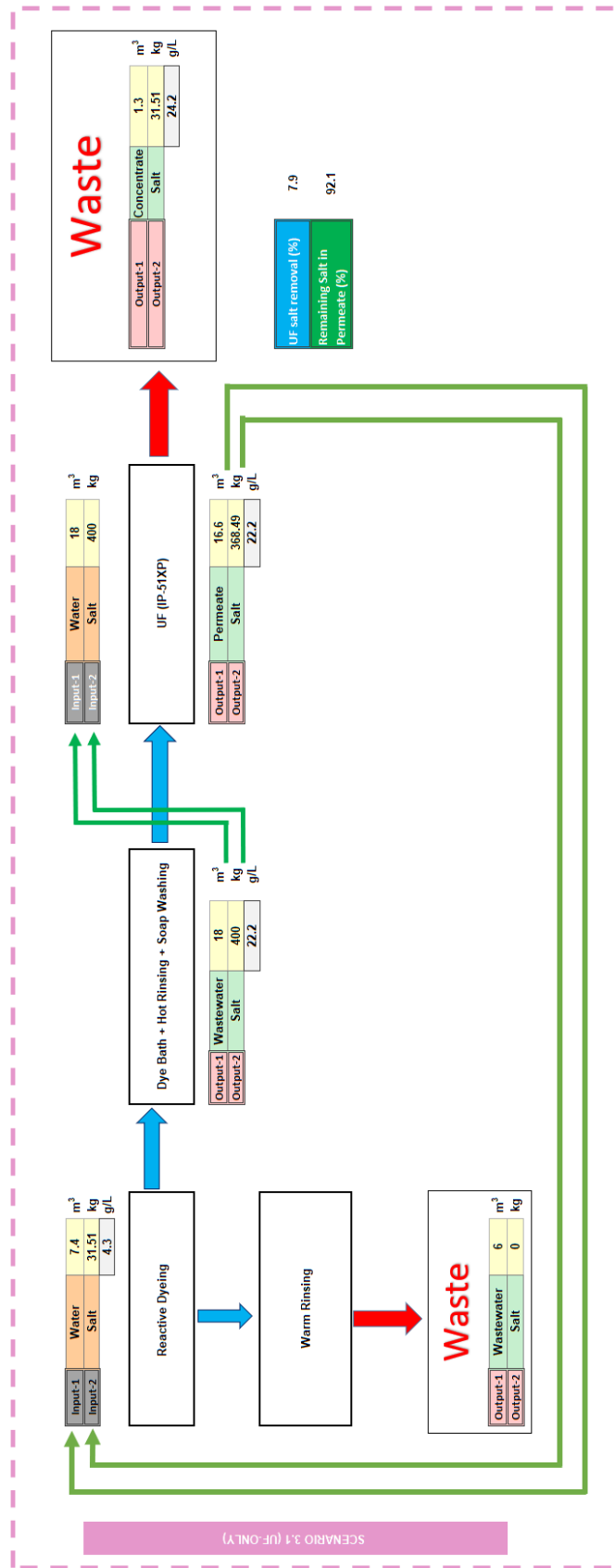


Figure C. 7. Scenario 3.1 Mass Balance Flow Chart

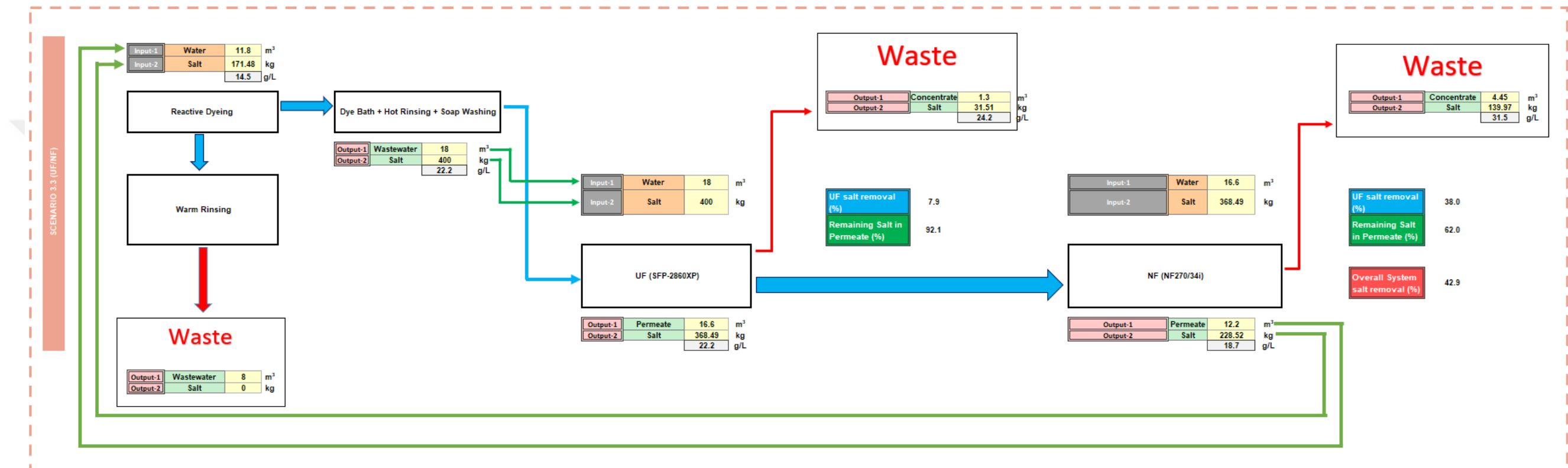


Figure C. 9. Scenario 3.3 Mass Balance Flow Chart

D. Details of ReCiPe 2016 Impact Assessment Method

Table D. 1. ReCiPe 2016 Perspectives and Definitions (National Institute for Public Health and the Environment, 2017)

Perspective	Definition
Individualistic (I)	“Based on the short-term interest, impact types that are undisputed, and technological optimism with regard to human adaptation”
Hierarchist (H)	“Based on scientific consensus with regard to the time frame and plausibility of impact mechanisms”
Egalitarian (E)	“The most precautionary perspective, taking into account the longest time frame and all impact pathways for which data is available”

Table D. 2. Details of Impact Categories and Calculation Steps in ReCiPe 2016 (Huijbregts et al., 2017)

Mid-Point Impact Category	Description of the Category	Mid-Point Unit	End-Point Impact Category	Mid-Point to End-Point Factors	End-Point Unit	Normalization Factors (Conversion to "Pt")
Global warming, Human health	"Years of life lost and disabled related to increased malaria, diarrhea, malnutrition and natural disasters due to increased global mean temperature."	yr/kg CO ₂ to air	Human Health	9.3E-07	DALY	41.7 Pt/DALY
Stratospheric ozone depletion	"Years of life lost and disabled related to increased skin cancer and cataract due to UV-exposure"	yr/kg CFC11 to air		9.3E-07	DALY	
Ionizing radiation	"Years of life lost and disabled related to an increase in cancer and hereditary diseases due to exposure to radiation"	yr/kBq Co-60 to air		8.5E-09	DALY	
Ozone formation, Human health	"Years of life lost related to an increase in respiratory diseases caused by exposure to ozone"	yr/kg NOx to air		9.1E-07	DALY	
Fine particulate matter formation	"Years of life lost related to an increase in cardiopulmonary and lung cancer caused by exposure to primary and secondary aerosols"	yr/kg PM2.5 to air		8.5E-09	DALY	

Table D. 2 (cont'd)

Mid-Point Impact Category	Description of the Category	Mid-Point Unit	End-Point Impact Category	Mid-Point to End-Point Factors	End-Point Unit	Normalization Factors (Conversion to "Pt")
Human carcinogenic toxicity	“Years of life lost and disabled due to cancer and non-cancer effects due to ingestion and inhalation of toxic substances”	yr/kg 1,4-DCB to air		3.3E-06	DALY	
Human non-carcinogenic toxicity		yr/kg 1,4-DCB to air		6.7E-09	DALY	
Water consumption, Human health	“Malnutrition caused by water shortage”	yr/m ³ water		2.2E-06	DALY	
Global warming, Terrestrial ecosystems	“Species loss related to changing biome distributions due to increased global temperature”	yr/kg CO ₂ to air	Ecosystems	2.8E-09	species.yr	676 Pt/ species.yr
Global warming, Freshwater ecosystems	“Fish species loss due to decrease river discharge”	yr/kg CO ₂ to air		7.7E-14	species.yr	
Ozone formation, Terrestrial ecosystems	“Loss of plant species due to increase in ozone exposure”	yr/kg NO _x to air		1.3E-07	species.yr	
Terrestrial acidification	“Loss of plant species due to decrease in soil pH”	species.yr/kg SO ₂ to air		2.1E-07	species.yr	

Table D. 2 (cont'd)

Mid-Point Impact Category	Description of the Category	Mid-Point Unit	End-Point Impact Category	Mid-Point to End-Point Factors	End-Point Unit	Normalization Factors (Conversion to "Pt")
Freshwater eutrophication	"Loss of aquatic species due to increased phosphorus concentrations"	species.yr/kg P to fresh water		6.1E-07	species.yr	
Marine eutrophication	"Loss of aquatic species due to increased nitrogen concentrations"	species.yr/kg N to marine water		1.7E-09	species.yr	
Terrestrial ecotoxicity	"Species loss due to chemical exposure in soils"	species.yr/kg 1,4-DCB to industrial soil		5.4E-08	species.yr	
Freshwater ecotoxicity	"Species loss due to chemical exposure in freshwater"	species.yr/kg 1,4-DCB to fresh water		7.0E-10	species.yr	
Marine ecotoxicity	"Species loss due to chemical exposure in marine waters"	species.yr/kg 1,4-DCB		1.1E-10	species.yr	
Land use	"Species loss due to different types of land use (agriculture, forestry, built up). Species loss caused by transformation of natural land to used land, including the	species/m ² annual crop land		8.9E-09	species.yr	

Table D. 2 (cont'd)

Mid-Point Impact Category	Description of the Category	Mid-Point Unit	End-Point Impact Category	Mid-Point to End-Point Factors	End-Point Unit	Normalization Factors (Conversion to "Pt")
	time it takes to back-transform to natural land"					
Water consumption, Terrestrial ecosystem	"Decrease in Net Primary Productivity because of water shortage as proxy for total species loss"	species.yr/m ³ water consumed		1.4E-08	species.yr	
Water consumption, Aquatic ecosystems	"Fish species loss due to decreased river discharge"	species.yr/m ³ water consumed		6.0E-13	species.yr	
Mineral resource scarcity	"Cost increase due to mineral extraction increase"	US2013 \$/kg Cu		0.23	USD2013	
Fossil resource scarcity	"Cost increase due to fossil extraction increase"	-US2013 \$/kg crude oil -US2013 \$/kg hard coal -US2013 \$/Nm ³ natural gas	Resources	0.46 0.03 0.30	USD2013	3.57E-05 Pt/ USD2013

E. Normalized Results of Life Cycle Impact Assessment

Table E. 1. Mid-point Impact Assessment Results of Jet Dyeing Scenarios

Mid-point Impact Categories (Pt)	Scenario 1.a	Scenario 1.1	Scenario 1.2	Scenario 1.3
Total	79.11	77.88	80.77	85.35
Global warming, Human health	29.36	29.26	30.22	31.34
Global warming, Terrestrial ecosystems	1.44	1.43	1.48	1.53
Global warming, Freshwater ecosystems	3.9E-05	3.9E-05	4.0E-05	4.2E-05
Stratospheric ozone depletion	8.1E-03	8.4E-03	8.2E-03	8.6E-03
Ionizing radiation	5.5E-03	5.5E-03	7.3E-03	8.2E-03
Ozone formation, Human health	6.0E-02	5.8E-02	6.0E-02	6.2E-02
Fine particulate matter formation	35.15	35.85	37.41	39.82
Ozone formation, Terrestrial ecosystems	1.4E-01	1.4E-01	1.4E-01	1.5E-01
Terrestrial acidification	3.9E-01	4.0E-01	4.1E-01	4.2E-01
Freshwater eutrophication	1.1E-01	1.0E-01	1.1E-01	1.3E-01
Marine eutrophication	4.7E-03	4.7E-03	4.7E-03	4.7E-03
Terrestrial ecotoxicity	1.1E-02	1.0E-02	9.8E-03	1.0E-02
Freshwater ecotoxicity	2.3E-02	2.1E-02	2.2E-02	2.3E-02
Marine ecotoxicity	1.8E-03	1.5E-03	1.7E-03	1.8E-03

Table E. 1 (cont'd)

Mid-point Impact Categories (Pt)	Scenario 1.a	Scenario 1.1	Scenario 1.2	Scenario 1.3
Human carcinogenic toxicity	2.92	2.76	2.94	3.17
Human non-carcinogenic toxicity	4.81	4.72	4.68	5.23
Land use	3.3E-01	3.3E-01	3.2E-01	3.4E-01
Mineral resource scarcity	2.5E-03	2.6E-03	2.4E-03	2.7E-03
Fossil resource scarcity	1.46	1.45	1.48	1.51
Water consumption, Human health	2.61	1.21	1.33	1.45
Water consumption, Terrestrial ecosystem	2.6E-01	1.2E-01	1.4E-01	1.5E-01
Water consumption, Aquatic ecosystem	1.4E-05	7.5E-06	8.2E-06	8.8E-06

Table E. 2. End-point Impact Assessment Results of Jet Dyeing Scenarios

End-point Impact Categories (Pt)	Scenario 1.a	Scenario 1.1	Scenario 1.2	Scenario 1.3
Human Health	74.9	73.9	76.7	81.1
Ecosystems	2.7	2.6	2.6	2.8
Resources	1.5	1.5	1.5	1.5

Table E. 3. Mid-point Impact Assessment Results of Jigger Dyeing Scenarios

Mid-point Impact Categories (Pt)	Scenario 2.a	Scenario 2.1	Scenario 2.2	Scenario 2.3
Total	52.57	49.96	52.63	55.75
Global warming, Human health	17.78	17.27	18.12	18.87
Global warming, Terrestrial ecosystems	0.87	0.84	0.89	0.92
Global warming, Freshwater ecosystems	2.4E-05	2.3E-05	2.4E-05	2.5E-05
Stratospheric ozone depletion	6.4E-03	6.5E-03	6.4E-03	6.7E-03
Ionizing radiation	3.4E-03	3.2E-03	4.6E-03	5.1E-03
Ozone formation, Human health	3.5E-02	3.2E-02	3.4E-02	3.6E-02
Fine particulate matter formation	23.54	23.30	24.69	26.27
Ozone formation, Terrestrial ecosystems	0.08	0.08	0.08	0.09
Terrestrial acidification	0.25	0.25	0.26	0.27
Freshwater eutrophication	0.08	0.08	0.09	0.09
Marine eutrophication	4.7E-03	4.7E-03	4.7E-03	4.7E-03
Terrestrial ecotoxicity	7.5E-03	6.7E-03	6.5E-03	7.1E-03
Freshwater ecotoxicity	2.1E-02	2.0E-02	2.1E-02	2.1E-02
Marine ecotoxicity	1.5E-03	1.2E-03	1.4E-03	1.5E-03
Human carcinogenic toxicity	2.45	2.20	2.37	2.54

Table E. 3 (cont'd)

Mid-point Impact Categories (Pt)	Scenario 2.a	Scenario 2.1	Scenario 2.2	Scenario 2.3
Human non-carcinogenic toxicity	4.00	3.68	3.73	4.13
Land use	0.29	0.28	0.28	0.29
Mineral resource scarcity	2.0E-03	2.0E-03	1.8E-03	2.0E-03
Fossil resource scarcity	0.85	0.83	0.86	0.88
Water consumption, Human health	2.09	0.98	1.09	1.20
Water consumption, Terrestrial ecosystem	0.21	0.10	0.11	0.12
Water consumption, Aquatic ecosystem	1.1E-05	6.3E-06	6.9E-06	7.5E-06

Table E. 4. End-point Impact Assessment Results of Jigger Dyeing Scenarios

End-point Impact Categories (Pt)	Scenario 2.a	Scenario 2.1	Scenario 2.2	Scenario 2.3
Human Health	49.90	47.50	50.00	53.10
Ecosystems	1.80	1.70	1.70	1.80
Resources	0.90	0.80	0.90	0.90

Table E. 5. Mid-point Impact Assessment Results of Pad Dyeing Scenarios

Mid-point Impact Categories (Pt)	Scenario 3.a	Scenario 3.1	Scenario 3.2	Scenario 3.3
Total	80.36	77.20	80.06	82.72
Global warming, Human health	30.46	29.73	30.59	31.24
Global warming, Terrestrial ecosystems	1.49	1.45	1.50	1.53
Global warming, Freshwater ecosystems	4.1E-05	4.0E-05	4.1E-05	4.2E-05
Stratospheric ozone depletion	8.2E-03	8.2E-03	8.1E-03	8.4E-03
Ionizing radiation	4.0E-03	3.7E-03	4.9E-03	5.4E-03
Ozone formation, Human health	0.06	0.06	0.06	0.06
Fine particulate matter formation	36.40	35.62	37.06	38.43
Ozone formation, Terrestrial ecosystems	0.15	0.14	0.14	0.15
Terrestrial acidification	0.41	0.41	0.41	0.42
Freshwater eutrophication	0.10	0.09	0.10	0.11
Marine eutrophication	4.7E-03	4.7E-03	4.7E-03	4.7E-03
Terrestrial ecotoxicity	0.01	0.01	0.01	0.01
Freshwater ecotoxicity	0.02	0.02	0.02	0.02
Marine ecotoxicity	1.8E-03	1.4E-03	1.6E-03	1.7E-03
Human carcinogenic toxicity	2.82	2.53	2.71	2.86

Table E. 5 (cont'd)

Mid-point Impact Categories (Pt)	Scenario 3.a	Scenario 3.1	Scenario 3.2	Scenario 3.3
Human non-carcinogenic toxicity	4.67	4.21	4.36	4.69
Land use	0.34	0.32	0.32	0.33
Mineral resource scarcity	2.5E-03	2.4E-03	2.4E-03	2.6E-03
Fossil resource scarcity	1.58	1.55	1.58	1.59
Water consumption, Human health	1.66	0.94	1.07	1.14
Water consumption, Terrestrial ecosystem	0.17	0.10	0.11	0.12
Water consumption, Aquatic ecosystem	9.4E-06	6.1E-06	6.8E-06	7.2E-06

Table E. 6. End-point Impact Assessment Results of Pad Dyeing Scenarios

End-point Impact Categories (Pt)	Scenario 3.a	Scenario 3.1	Scenario 3.2	Scenario 3.3
Human Health	76.10	73.10	75.90	78.40
Ecosystems	2.70	2.60	2.60	2.70
Resources	1.60	1.60	1.60	1.60

F. Process Contributions to Mid-Point Impact Categories

Jet Dyeing Process Contributions to Mid-Point Impact Categories

Table F. 1. Scenario 1.a (Jet-Baseline) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	2.9E+01	1.4E+00	3.9E-05	8.1E-03	5.5E-03	6.0E-02	3.5E+01	1.4E-01	3.9E-01	1.1E-01	4.7E-03
Air Emissions	2.9E+01	1.4E+00	3.9E-05	8.1E-03	5.5E-03	6.0E-02	3.5E+01	1.4E-01	3.9E-01	0	0
Water Emissions	0	0	0	0	1.5E-05	0	0	0	0	1.1E-01	4.7E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	2.0E+00	1.0E-01	2.7E-06	4.1E-04	2.6E-03	3.7E-03	4.2E+00	8.5E-03	2.2E-02	1.8E-02	2.9E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0

Table F. 1 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Jet_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05

Table F. 1 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.6E+00	7.9E-02	2.2E-06	3.8E-04	6.8E-04	5.0E-03	2.8E+00	1.2E-02	1.5E-02	1.6E-02	7.7E-06
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	1.6E+01	7.8E-01	2.1E-05	2.2E-03	1.3E-03	1.9E-02	9.0E+00	4.6E-02	1.4E-01	2.5E-02	4.1E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07

Table F. 1 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Water, completely softened {RER} water production, completely softened Conseq, S	1.9E-01	9.5E-03	2.6E-07	1.6E-04	4.3E-04	3.9E-04	2.7E-01	9.1E-04	2.2E-03	1.5E-03	3.1E-07

Table F. 2. Scenario 1.a (Jet-Baseline) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	1.1E-02	2.3E-02	1.8E-03	2.9E+00	4.8E+00	3.3E-01	2.5E-03	1.5E+00	2.6E+00	2.6E-01	1.4E-05
Air Emissions	1.1E-02	1.1E-05	5.0E-05	1.2E-01	3.0E-01	0	0	0	0	0	0
Water Emissions	5.2E-07	2.3E-02	1.7E-03	2.8E+00	4.4E+00	0	0	0	6.6E+01	-	-7.0E-04
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0

Table F. 2 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07
Electricity, high voltage {GLO} market group for Conseq, S	1.9E-04	7.5E-04	1.5E-04	3.0E-01	5.2E-01	8.9E-03	1.2E-04	5.4E-02	9.7E-03	1.1E-03	2.8E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Jet_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07

Table F. 2 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTP _c (Pt)	HTP _{nc} (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	2.6E-14	1.4E-02	5.0E-05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E-09
Soap {GLO} market for Conseq, S	3.0E-04	3.2E-04	4.6E-05	7.7E-02	1.4E-01	9.0E-02	8.0E-05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E-04	-3.6E-07	1.5E-06	2.4E-02	5.1E-02	5.0E-03	4.6E-06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E-08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E-04	3.8E-04	7.7E-05	1.5E-01	2.8E-01	2.3E-02	3.4E-05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.7E-03	2.0E-03	3.9E-04	5.0E-01	9.5E-01	3.1E-02	3.7E-04	4.4E-02	5.2E-02	5.8E-03	4.0E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E-05	2.2E-04	4.4E-05	8.7E-02	1.6E-01	1.4E-02	1.6E-05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0

Table F. 2 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	4.7E-03	1.2E-03	3.0E-04	5.0E-01	8.7E-01	5.8E-02	6.3E-04	8.7E-01	1.1E-02	2.0E-03	1.2E-07
Sulfur trioxide {GLO} market for Conseq, S	1.2E-03	6.4E-04	1.4E-04	1.2E-01	5.8E-01	4.7E-03	5.9E-04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E-05	1.3E-04	2.5E-05	2.2E-02	3.8E-02	1.1E-03	2.6E-05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E-06	2.0E-06	4.1E-07	2.2E-03	9.8E-04	1.1E-05	3.5E-06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Water, completely softened {RER} water production, completely softened Conseq, S	1.0E-04	2.2E-04	4.2E-05	4.6E-02	6.4E-02	4.6E-03	1.3E-04	6.8E-03	2.0E+00	2.0E-01	9.0E-06

Table F. 3. Scenario 1.1 (Jet-UF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	2.9E+01	1.4E+00	3.9E-05	8.4E-03	5.5E-03	5.8E-02	3.6E+01	1.4E-01	4.0E-01	1.1E-01	4.7E-03
Air Emissions	2.9E+01	1.4E+00	3.9E-05	8.4E-03	5.5E-03	5.8E-02	3.6E+01	1.4E-01	4.0E-01	0	0
Water Emissions	0	0	0	0	1.6E-05	0	0	0	0	1.1E-01	4.7E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	6.2E-02	3.0E-03	8.3E-08	8.3E-05	-5.8E-06	1.7E-04	1.8E-01	3.9E-04	1.3E-03	6.5E-04	5.3E-07
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	2.0E+00	1.0E-01	2.7E-06	4.1E-04	2.6E-03	3.7E-03	4.2E+00	8.5E-03	2.2E-02	1.8E-02	2.9E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	3.8E-01	1.9E-02	5.1E-07	7.6E-05	4.9E-04	6.8E-04	7.8E-01	1.6E-03	4.0E-03	3.3E-03	5.5E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07

Table F. 3 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	1.2E-02	5.7E-04	1.6E-08	1.1E-05	2.1E-05	2.4E-05	1.8E-02	5.5E-05	1.2E-04	7.4E-06	3.2E-08
Jet_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_only UF_sludge	0	0	0	0	0	0	0	0	0	2.1E-03	1.4E-06
Jet_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05

Table F. 3 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.2E-01	5.8E-03	1.6E-07	2.8E-05	5.0E-05	3.7E-04	2.1E-01	8.6E-04	1.1E-03	1.1E-03	5.6E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	2.2E-01	1.1E-02	2.9E-07	2.8E-05	-2.0E-04	6.0E-04	8.5E-01	1.4E-03	7.0E-03	4.4E-03	4.9E-07
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	8.5E-01	4.2E-02	1.1E-06	5.6E-04	7.0E-04	1.6E-03	1.7E+00	3.8E-03	9.7E-03	9.2E-03	1.9E-06
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	1.6E+01	7.8E-01	2.1E-05	2.2E-03	1.3E-03	1.9E-02	9.0E+00	4.6E-02	1.4E-01	2.5E-02	4.1E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08

Table F. 3 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Water, completely softened {RER} water production, completely softened Conseq, S	5.9E-02	2.9E-03	7.9E-08	4.7E-05	1.3E-04	1.2E-04	8.2E-02	2.8E-04	6.6E-04	4.5E-04	9.5E-08

Table F. 4. Scenario 1.1 (Jet-UF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTP _c (Pt)	HTP _{nc} (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	1.0E-02	2.1E-02	1.6E-03	2.8E+00	4.7E+00	3.3E-01	2.6E-03	1.5E+00	1.2E+00	1.3E-01	7.5E-06
Air Emissions	1.0E-02	1.0E-05	4.7E-05	1.1E-01	3.0E-01	0	0	0	0	0	0
Water Emissions	5.1E-07	2.1E-02	1.5E-03	2.6E+00	4.3E+00	0	0	0	-	-	-7.5E-04
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	2.6E-05	3.4E-05	6.7E-06	1.2E-02	2.3E-02	2.3E-03	9.8E-06	1.3E-03	3.3E-03	3.3E-04	1.4E-07
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07

Table F. 4 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Electricity, high voltage {GLO} market group for Conseq, S	1.9E-04	7.5E-04	1.5E-04	3.0E-01	5.2E-01	8.9E-03	1.2E-04	5.4E-02	9.7E-03	1.1E-03	2.8E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	3.5E-05	1.4E-04	2.8E-05	5.7E-02	9.6E-02	1.7E-03	2.2E-05	1.0E-02	1.8E-03	2.1E-04	5.3E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	5.0E-06	9.4E-06	1.8E-06	1.6E-03	2.8E-03	-2.8E-04	2.1E-06	5.8E-04	8.9E-04	8.3E-05	5.9E-09
Jet_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_only UF_sludge	1.1E-09	6.1E-05	1.1E-05	2.1E-03	3.5E-03	0	0	0	0	0	0
Jet_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07

Table F. 4 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTP _c (Pt)	HTP _{nc} (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	2.6E-14	1.4E-02	5.0E-05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E-09
Soap {GLO} market for Conseq, S	3.0E-04	3.2E-04	4.6E-05	7.7E-02	1.4E-01	9.0E-02	8.0E-05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E-04	-3.6E-07	1.5E-06	2.4E-02	5.1E-02	5.0E-03	4.6E-06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E-08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E-04	3.8E-04	7.7E-05	1.5E-01	2.8E-01	2.3E-02	3.4E-05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.2E-04	1.4E-04	2.8E-05	3.7E-02	6.9E-02	2.2E-03	2.7E-05	3.2E-03	3.8E-03	4.2E-04	2.9E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E-05	2.2E-04	4.4E-05	8.7E-02	1.6E-01	1.4E-02	1.6E-05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	9.0E-05	2.0E-04	4.1E-05	8.2E-02	1.5E-01	1.3E-02	1.5E-05	-3.2E-04	2.1E-02	2.2E-03	1.0E-07
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	9.4E-04	7.0E-04	1.5E-04	1.9E-01	5.9E-01	8.5E-03	4.8E-04	2.1E-02	4.5E-02	4.5E-03	2.0E-07

Table F. 4 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	4.7E-03	1.2E-03	3.0E-04	5.0E-01	8.7E-01	5.8E-02	6.3E-04	8.7E-01	1.1E-02	2.0E-03	1.2E-07
Sulfur trioxide {GLO} market for Conseq, S	1.2E-03	6.4E-04	1.4E-04	1.2E-01	5.8E-01	4.7E-03	5.9E-04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E-05	1.3E-04	2.5E-05	2.2E-02	3.8E-02	1.1E-03	2.6E-05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E-06	2.0E-06	4.1E-07	2.2E-03	9.8E-04	1.1E-05	3.5E-06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Water, completely softened {RER} water production, completely softened Conseq, S	3.1E-05	6.6E-05	1.3E-05	1.4E-02	2.0E-02	1.4E-03	4.1E-05	2.1E-03	6.2E-01	6.1E-02	2.8E-06

Table F. 5. Scenario 1.2 (Jet-NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	3.0E+01	1.5E+00	4.0E-05	8.2E-03	7.3E-03	6.0E-02	3.7E+01	1.4E-01	4.1E-01	1.2E-01	4.7E-03
Air Emissions	3.0E+01	1.5E+00	4.0E-05	8.2E-03	7.3E-03	6.0E-02	3.7E+01	1.4E-01	4.1E-01	0	0

Table F. 5 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Water Emissions	0	0	0	0	2.1E-05	0	0	0	0	1.2E-01	4.7E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	2.0E+00	1.0E-01	2.7E-06	4.1E-04	2.6E-03	3.7E-03	4.2E+00	8.5E-03	2.2E-02	1.8E-02	2.9E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	2.0E+00	9.9E-02	2.7E-06	4.0E-04	2.6E-03	3.6E-03	4.1E+00	8.4E-03	2.1E-02	1.7E-02	2.9E-06
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	7.8E-03	3.8E-04	1.0E-08	7.6E-06	1.4E-05	1.6E-05	1.2E-02	3.7E-05	7.8E-05	4.9E-06	2.2E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Jet_only NF_sludge	0	0	0	0	0	0	0	0	0	6.9E-03	3.9E-06

Table F. 5 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Jet_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04
Non-ionic surfactant {GLO} market for non- ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	1.2E-02	5.7E-04	1.6E-08	3.2E-06	-5.9E-07	4.6E-05	7.2E-02	1.1E-04	1.1E-03	2.9E-04	1.7E-08
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	5.2E-01	2.5E-02	6.9E-07	1.2E-04	2.2E-04	1.6E-03	9.0E-01	3.8E-03	4.9E-03	5.0E-03	2.5E-06
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	3.8E-02	1.8E-03	5.0E-08	4.9E-06	-3.4E-05	1.0E-04	1.5E-01	2.4E-04	1.2E-03	7.7E-04	8.6E-08

Table F. 5 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	1.6E+01	7.8E-01	2.1E-05	2.2E-03	1.3E-03	1.9E-02	9.0E+00	4.6E-02	1.4E-01	2.5E-02	4.1E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Water, completely softened {RER} water production, completely softened Conseq, S	7.4E-02	3.6E-03	9.9E-08	6.0E-05	1.6E-04	1.5E-04	1.0E-01	3.5E-04	8.3E-04	5.7E-04	1.2E-07

Table F. 6. Scenario 1.2 (Jet-NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	9.8E-03	2.2E-02	1.7E-03	2.9E+00	4.7E+00	3.2E-01	2.4E-03	1.5E+00	1.3E+00	1.4E-01	8.2E-06
Air Emissions	9.8E-03	1.0E-05	4.6E-05	1.1E-01	2.7E-01	0	0	0	0	0	0
Water Emissions	5.1E-07	2.2E-02	1.6E-03	2.8E+00	4.3E+00	0	0	0	-	-	-1.0E-03
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07
Electricity, high voltage {GLO} market group for Conseq, S	1.9E-04	7.5E-04	1.5E-04	3.0E-01	5.2E-01	8.9E-03	1.2E-04	5.4E-02	9.7E-03	1.1E-03	2.8E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.8E-04	7.4E-04	1.5E-04	3.0E-01	5.1E-01	8.8E-03	1.1E-04	5.4E-02	9.5E-03	1.1E-03	2.8E-07
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08

Table F. 6 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	3.3E-06	6.3E-06	1.2E-06	1.1E-03	1.9E-03	-1.9E-04	1.4E-06	3.9E-04	5.9E-04	5.5E-05	3.9E-09
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Jet_only NF_sludge	1.6E-09	6.0E-04	1.1E-04	1.8E-02	3.1E-02	0	0	0	0	0	0
Jet_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	9.6E-06	2.1E-05	4.5E-06	5.7E-02	1.1E-02	9.6E-04	7.7E-05	3.8E-04	4.8E-03	4.8E-04	3.0E-08
Reactive Orange 12/Golden Yellow HR	2.6E-14	1.4E-02	5.0E-05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E-09
Soap {GLO} market for Conseq, S	3.0E-04	3.2E-04	4.6E-05	7.7E-02	1.4E-01	9.0E-02	8.0E-05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E-04	-3.6E-07	1.5E-06	2.4E-02	5.1E-02	5.0E-03	4.6E-06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E-08

Table F. 6 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E-04	3.8E-04	7.7E-05	1.5E-01	2.8E-01	2.3E-02	3.4E-05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	5.3E-04	6.3E-04	1.2E-04	1.6E-01	3.0E-01	9.8E-03	1.2E-04	1.4E-02	1.7E-02	1.8E-03	1.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E-05	2.2E-04	4.4E-05	8.7E-02	1.6E-01	1.4E-02	1.6E-05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	1.6E-05	3.5E-05	7.2E-06	1.4E-02	2.6E-02	2.2E-03	2.6E-06	-5.6E-05	3.6E-03	3.9E-04	1.7E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	4.7E-03	1.2E-03	3.0E-04	5.0E-01	8.7E-01	5.8E-02	6.3E-04	8.7E-01	1.1E-02	2.0E-03	1.2E-07
Sulfur trioxide {GLO} market for Conseq, S	1.2E-03	6.4E-04	1.4E-04	1.2E-01	5.8E-01	4.7E-03	5.9E-04	1.4E-02	1.1E-01	1.0E-02	4.7E-07

Table F. 6 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E-05	1.3E-04	2.5E-05	2.2E-02	3.8E-02	1.1E-03	2.6E-05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E-06	2.0E-06	4.1E-07	2.2E-03	9.8E-04	1.1E-05	3.5E-06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Water, completely softened {RER} water production, completely softened Conseq, S	3.9E-05	8.3E-05	1.6E-05	1.8E-02	2.5E-02	1.7E-03	5.1E-05	2.6E-03	7.8E-01	7.7E-02	3.5E-06

Table F. 7. Scenario 1.3 (Jet-UF+NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	3.1E+01	1.5E+00	4.2E-05	8.6E-03	8.2E-03	6.2E-02	4.0E+01	1.5E-01	4.2E-01	1.3E-01	4.7E-03
Air Emissions	3.1E+01	1.5E+00	4.2E-05	8.6E-03	8.2E-03	6.2E-02	4.0E+01	1.5E-01	4.2E-01	0	0
Water Emissions	0	0	0	0	2.4E-05	0	0	0	0	1.3E-01	4.7E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	3.8E-02	1.9E-03	5.1E-08	5.1E-05	-3.5E-06	1.0E-04	1.1E-01	2.4E-04	8.2E-04	4.0E-04	3.3E-07

Table F. 7 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	2.0E+00	1.0E-01	2.7E-06	4.1E-04	2.6E-03	3.7E-03	4.2E+00	8.5E-03	2.2E-02	1.8E-02	2.9E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	2.1E+00	1.0E-01	2.8E-06	4.1E-04	2.6E-03	3.7E-03	4.2E+00	8.6E-03	2.2E-02	1.8E-02	3.0E-06
Electricity, high voltage {GLO} market group for Conseq, S_UF	4.0E-01	2.0E-02	5.4E-07	8.0E-05	5.1E-04	7.2E-04	8.2E-01	1.7E-03	4.3E-03	3.5E-03	5.8E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	5.2E-03	2.5E-04	6.9E-09	5.0E-06	9.5E-06	1.0E-05	8.1E-03	2.5E-05	5.2E-05	3.3E-06	1.4E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	6.5E-03	3.2E-04	8.6E-09	6.3E-06	1.2E-05	1.3E-05	1.0E-02	3.1E-05	6.5E-05	4.1E-06	1.8E-08
Jet_ only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_ only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	5.2E-03	2.7E-06
Jet_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	2.1E-03	1.4E-06
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04

Table F. 7 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	1.1E-02	5.3E-04	1.4E-08	2.9E-06	-5.5E-07	4.3E-05	6.7E-02	1.0E-04	1.1E-03	2.7E-04	1.5E-08
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	6.1E-01	3.0E-02	8.1E-07	1.4E-04	2.6E-04	1.9E-03	1.1E+00	4.4E-03	5.7E-03	5.9E-03	2.9E-06
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	3.5E-02	1.7E-03	4.7E-08	4.5E-06	-3.2E-05	9.7E-05	1.4E-01	2.2E-04	1.1E-03	7.2E-04	8.0E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	9.1E-02	4.5E-03	1.2E-07	1.2E-05	-8.3E-05	2.5E-04	3.6E-01	5.9E-04	3.0E-03	1.9E-03	2.1E-07
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	4.4E-01	2.2E-02	5.9E-07	2.9E-04	3.6E-04	8.5E-04	8.6E-01	2.0E-03	5.0E-03	4.7E-03	9.8E-07

Table F. 7 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	1.6E+01	7.8E-01	2.1E-05	2.2E-03	1.3E-03	1.9E-02	9.0E+00	4.6E-02	1.4E-01	2.5E-02	4.1E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Water, completely softened {RER} water production, completely softened Conseq, S	8.2E-02	4.0E-03	1.1E-07	6.5E-05	1.8E-04	1.6E-04	1.1E-01	3.8E-04	9.1E-04	6.2E-04	1.3E-07

Table F. 8. Scenario 1.3 (Jet-UF+NF) Process Contributions to Mid-point Impact Categories (TETP – AWC/P)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPe (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	1.0E-02	2.3E-02	1.8E-03	3.2E+00	5.2E+00	3.4E-01	2.7E-03	1.5E+00	1.5E+00	1.5E-01	8.8E-06
Air Emissions	1.0E-02	1.1E-05	4.9E-05	1.2E-01	3.1E-01	0	0	0	0	0	0

Table F. 8 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTP _c (Pt)	HTP _{nc} (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Water Emissions	5.1E-07	2.3E-02	1.8E-03	3.0E+00	4.8E+00	0	0	0	- 9.9E+01	- 1.1E+01	-1.1E-03
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	1.6E-05	2.1E-05	4.1E-06	7.4E-03	1.4E-02	1.4E-03	6.0E-06	7.8E-04	2.0E-03	2.0E-04	8.7E-08
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07
Electricity, high voltage {GLO} market group for Conseq, S	1.9E-04	7.5E-04	1.5E-04	3.0E-01	5.2E-01	8.9E-03	1.2E-04	5.4E-02	9.7E-03	1.1E-03	2.8E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.9E-04	7.6E-04	1.5E-04	3.1E-01	5.2E-01	9.0E-03	1.2E-04	5.5E-02	9.8E-03	1.2E-03	2.9E-07
Electricity, high voltage {GLO} market group for Conseq, S_UF	3.7E-05	1.5E-04	3.0E-05	6.0E-02	1.0E-01	1.8E-03	2.3E-05	1.1E-02	1.9E-03	2.3E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	2.2E-06	4.2E-06	8.0E-07	7.2E-04	1.3E-03	-1.2E-04	9.2E-07	2.6E-04	3.9E-04	3.7E-05	2.6E-09

Table F. 8 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	2.8E-06	5.2E-06	1.0E-06	8.9E-04	1.6E-03	-1.6E-04	1.1E-06	3.2E-04	4.9E-04	4.6E-05	3.3E-09
Jet only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jet UF+NF_NF_sludge	6.2E-10	5.4E-04	9.9E-05	1.6E-02	2.8E-02	0	0	0	0	0	0
Jet UF+NF_UF_sludge	1.1E-09	6.1E-05	1.1E-05	2.1E-03	3.5E-03	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	8.9E-06	2.0E-05	4.2E-06	5.3E-02	1.1E-02	8.9E-04	7.1E-05	3.5E-04	4.4E-03	4.4E-04	2.8E-08
Reactive Orange 12/Golden Yellow HR	2.6E-14	1.4E-02	5.0E-05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E-09
Soap {GLO} market for Conseq, S	3.0E-04	3.2E-04	4.6E-05	7.7E-02	1.4E-01	9.0E-02	8.0E-05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E-04	-3.6E-07	1.5E-06	2.4E-02	5.1E-02	5.0E-03	4.6E-06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E-08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E-04	3.8E-04	7.7E-05	1.5E-01	2.8E-01	2.3E-02	3.4E-05	2.5E-04	3.8E-02	4.1E-03	1.8E-07

Table F. 8 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sodium chloride, powder {GLO} market for Conseq, S	6.2E-04	7.4E-04	1.5E-04	1.9E-01	3.6E-01	1.1E-02	1.4E-04	1.7E-02	2.0E-02	2.2E-03	1.5E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E-05	2.2E-04	4.4E-05	8.7E-02	1.6E-01	1.4E-02	1.6E-05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	1.5E-05	3.3E-05	6.7E-06	1.3E-02	2.4E-02	2.0E-03	2.4E-06	-5.2E-05	3.3E-03	3.6E-04	1.6E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	3.8E-05	8.6E-05	1.7E-05	3.4E-02	6.4E-02	5.3E-03	6.3E-06	-1.4E-04	8.7E-03	9.5E-04	4.2E-08
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	4.9E-04	3.6E-04	7.7E-05	9.7E-02	3.0E-01	4.4E-03	2.5E-04	1.1E-02	2.3E-02	2.3E-03	1.0E-07
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	4.7E-03	1.2E-03	3.0E-04	5.0E-01	8.7E-01	5.8E-02	6.3E-04	8.7E-01	1.1E-02	2.0E-03	1.2E-07
Sulfur trioxide {GLO} market for Conseq, S	1.2E-03	6.4E-04	1.4E-04	1.2E-01	5.8E-01	4.7E-03	5.9E-04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E-05	1.3E-04	2.5E-05	2.2E-02	3.8E-02	1.1E-03	2.6E-05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07

Table F. 8 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Tap water {GLO} market group for Conseq, S	1.2E-06	2.0E-06	4.1E-07	2.2E-03	9.8E-04	1.1E-05	3.5E-06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Water, completely softened {RER} water production, completely softened Conseq, S	4.3E-05	9.1E-05	1.8E-05	2.0E-02	2.7E-02	1.9E-03	5.6E-05	2.9E-03	8.6E-01	8.4E-02	3.8E-06

Jigger Dyeing Process Contributions to Mid-Point Impact Categories

Table F. 9. Scenario 2.a (Jigger-Baseline) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	1.8E+01	8.7E-01	2.4E-05	6.4E-03	3.4E-03	3.5E-02	2.4E+01	8.3E-02	2.5E-01	8.5E-02	4.7E-03
Air Emissions	1.8E+01	8.7E-01	2.4E-05	6.4E-03	3.4E-03	3.5E-02	2.4E+01	8.3E-02	2.5E-01	0	0
Water Emissions	0	0	0	0	9.8E-06	0	0	0	0	8.5E-02	4.7E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07

Table F. 9 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Electricity, high voltage {GLO} market group for Conseq, S	1.2E+00	5.8E-02	1.6E-06	2.4E-04	1.5E-03	2.1E-03	2.4E+00	5.0E-03	1.3E-02	1.0E-02	1.7E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Jigger_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04
Non-ionic surfactant {GLO} market for non- ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03

Table F. 9 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.6E+00	7.9E-02	2.2E-06	3.8E-04	6.8E-04	5.0E-03	2.8E+00	1.2E-02	1.5E-02	1.6E-02	7.7E-06
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	5.3E+00	2.6E-01	7.1E-06	7.4E-04	4.4E-04	6.5E-03	3.0E+00	1.5E-02	4.5E-02	8.3E-03	1.4E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07

Table F. 9 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Water, completely softened {RER} water production, completely softened Conseq, S	1.5E-01	7.1E-03	1.9E-07	1.2E-04	3.2E-04	2.9E-04	2.0E-01	6.8E-04	1.6E-03	1.1E-03	2.3E-07

Table F. 10. Scenario 2.a (Jigger-Baseline) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	7.5E-03	2.1E-02	1.5E-03	2.5E+00	4.0E+00	2.9E-01	2.0E-03	8.5E-01	2.1E+00	2.1E-01	1.1E-05
Air Emissions	7.5E-03	8.0E-06	3.4E-05	1.0E-01	2.3E-01	0	0	0	0	0	0
Water Emissions	5.2E-07	2.1E-02	1.5E-03	2.3E+00	3.7E+00	0	0	0	-	-	-5.2E-04
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07

Table F. 10 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPe (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Electricity, high voltage {GLO} market group for Conseq, S	1.1E-04	4.4E-04	8.8E-05	1.8E-01	3.0E-01	5.2E-03	6.8E-05	3.2E-02	5.6E-03	6.7E-04	1.6E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Jigger_only_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_only_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non- ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0

Table F. 10 (cont'd)

Processes	TE/TP (Pt)	FETP (Pt)	METP (Pt)	HTP _c (Pt)	HTP _{nc} (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Reactive Orange 12/Golden Yellow HR	2.6E-14	1.4E-02	5.0E-05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E-09
Soap {GLO} market for Conseq, S	3.0E-04	3.2E-04	4.6E-05	7.7E-02	1.4E-01	9.0E-02	8.0E-05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E-04	-3.6E-07	1.5E-06	2.4E-02	5.1E-02	5.0E-03	4.6E-06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E-08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E-04	3.8E-04	7.7E-05	1.5E-01	2.8E-01	2.3E-02	3.4E-05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.7E-03	2.0E-03	3.9E-04	5.0E-01	9.5E-01	3.1E-02	3.7E-04	4.4E-02	5.2E-02	5.8E-03	4.0E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E-05	2.2E-04	4.4E-05	8.7E-02	1.6E-01	1.4E-02	1.6E-05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08

Table F. 10 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Steam, in chemical industry {RER} production Conseq, S	1.6E- 03	4.1E- 04	1.0E- 04	1.7E-01	2.9E-01	1.9E- 02	2.1E- 04	2.9E- 01	3.8E-03	6.8E-04	4.1E-08
Sulfur trioxide {GLO} market for Conseq, S	1.2E- 03	6.4E- 04	1.4E- 04	1.2E-01	5.8E-01	4.7E- 03	5.9E- 04	1.4E- 02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E- 05	1.3E- 04	2.5E- 05	2.2E-02	3.8E-02	1.1E- 03	2.6E- 05	-9.8E- 03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E- 06	2.0E- 06	4.1E- 07	2.2E-03	9.8E-04	1.1E- 05	3.5E- 06	8.5E- 05	1.7E-03	3.8E-04	8.2E-08
Water, completely softened {RER} water production, completely softened Conseq, S	7.6E- 05	1.6E- 04	3.1E- 05	3.5E-02	4.8E-02	3.4E- 03	1.0E- 04	5.1E- 03	1.5E+00	1.5E-01	6.8E-06

Table F. 11. Scenario 2.1 (Jigger-UF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	1.7E+01	8.4E-01	2.3E-05	6.5E- 03	3.2E- 03	3.2E- 02	2.3E+01	7.7E- 02	2.5E- 01	7.6E- 02	4.7E- 03
Air Emissions	1.7E+01	8.5E-01	2.3E-05	6.5E- 03	3.2E- 03	3.2E- 02	2.3E+01	7.7E- 02	2.5E- 01	0	0
Water Emissions	0	0	0	0	9.3E- 06	0	0	0	0	7.6E- 02	4.7E- 03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E- 04	7.6E- 05	3.0E- 03	3.1E+00	7.1E- 03	3.1E- 02	1.2E- 02	1.5E- 06

Table F. 11 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	4.6E-02	2.2E-03	6.1E-08	6.0E-05	-4.2E-06	1.2E-04	1.3E-01	2.8E-04	9.8E-04	4.7E-04	3.9E-07
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	1.2E+00	5.8E-02	1.6E-06	2.4E-04	1.5E-03	2.1E-03	2.4E+00	5.0E-03	1.3E-02	1.0E-02	1.7E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	2.6E-01	1.3E-02	3.5E-07	5.2E-05	3.3E-04	4.6E-04	5.3E-01	1.1E-03	2.7E-03	2.2E-03	3.7E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	9.0E-03	4.4E-04	1.2E-08	8.8E-06	1.7E-05	1.8E-05	1.4E-02	4.3E-05	9.1E-05	5.8E-06	2.5E-08
Jigger_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_only UF_sludge	0	0	0	0	0	0	0	0	0	2.1E-03	1.4E-06
Jigger_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04

Table F. 11 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.2E-01	5.8E-03	1.6E-07	2.8E-05	5.0E-05	3.7E-04	2.1E-01	8.6E-04	1.1E-03	1.1E-03	5.6E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	1.6E-01	7.9E-03	2.2E-07	2.1E-05	-1.5E-04	4.5E-04	6.3E-01	1.0E-03	5.2E-03	3.3E-03	3.7E-07
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	6.2E-01	3.0E-02	8.3E-07	4.1E-04	5.1E-04	1.2E-03	1.2E+00	2.8E-03	7.1E-03	6.7E-03	1.4E-06
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06

Table F. 11 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	5.3E+00	2.6E-01	7.1E-06	7.4E-04	4.4E-04	6.5E-03	3.0E+00	1.5E-02	4.5E-02	8.3E-03	1.4E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Water, completely softened {RER} water production, completely softened Conseq, S	4.0E-02	1.9E-03	5.3E-08	3.2E-05	8.7E-05	7.9E-05	5.5E-02	1.9E-04	4.4E-04	3.0E-04	6.4E-08

Table F. 12. Scenario 2.1 (Jigger-UF) Process Contributions to Mid-point Impact Categories (TETP – AWCp)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	6.7E-03	2.0E-02	1.2E-03	2.2E+00	3.7E+00	2.8E-01	2.0E-03	8.3E-01	9.8E-01	1.0E-01	6.3E-06
Air Emissions	6.7E-03	6.8E-06	3.0E-05	8.6E-02	2.2E-01	0	0	0	0	0	0
Water Emissions	5.1E-07	2.0E-02	1.2E-03	2.1E+00	3.4E+00	0	0	0	- 4.9E+01	- 5.4E+00	-5.1E-04

Table F. 12 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	1.9E-05	2.5E-05	4.9E-06	8.9E-03	1.7E-02	1.7E-03	7.2E-06	9.4E-04	2.4E-03	2.4E-04	1.0E-07
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07
Electricity, high voltage {GLO} market group for Conseq, S	1.1E-04	4.4E-04	8.8E-05	1.8E-01	3.0E-01	5.2E-03	6.8E-05	3.2E-02	5.6E-03	6.7E-04	1.6E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	2.4E-05	9.5E-05	1.9E-05	3.8E-02	6.5E-02	1.1E-03	1.5E-05	6.9E-03	1.2E-03	1.5E-04	3.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	3.9E-06	7.3E-06	1.4E-06	1.3E-03	2.2E-03	-2.2E-04	1.6E-06	4.5E-04	6.9E-04	6.5E-05	4.6E-09
Jigger_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_only UF_sludge	1.1E-09	6.1E-05	1.1E-05	2.1E-03	3.4E-03	0	0	0	0	0	0

Table F. 12 (cont'd)

Processes	TE/TP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Jigger UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non- ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	2.6E-14	1.4E-02	5.0E-05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E-09
Soap {GLO} market for Conseq, S	3.0E-04	3.2E-04	4.6E-05	7.7E-02	1.4E-01	9.0E-02	8.0E-05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E-04	-3.6E-07	1.5E-06	2.4E-02	5.1E-02	5.0E-03	4.6E-06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E-08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E-04	3.8E-04	7.7E-05	1.5E-01	2.8E-01	2.3E-02	3.4E-05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.2E-04	1.4E-04	2.8E-05	3.7E-02	6.9E-02	2.2E-03	2.7E-05	3.2E-03	3.8E-03	4.2E-04	2.9E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E-05	2.2E-04	4.4E-05	8.7E-02	1.6E-01	1.4E-02	1.6E-05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0

Table F. 12 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	6.7E-05	1.5E-04	3.1E-05	6.1E-02	1.1E-01	9.4E-03	1.1E-05	-2.4E-04	1.5E-02	1.7E-03	7.4E-08
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	6.8E-04	5.1E-04	1.1E-04	1.4E-01	4.3E-01	6.2E-03	3.5E-04	1.5E-02	3.2E-02	3.3E-03	1.4E-07
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	1.6E-03	4.1E-04	1.0E-04	1.7E-01	2.9E-01	1.9E-02	2.1E-04	2.9E-01	3.8E-03	6.8E-04	4.1E-08
Sulfur trioxide {GLO} market for Conseq, S	1.2E-03	6.4E-04	1.4E-04	1.2E-01	5.8E-01	4.7E-03	5.9E-04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E-05	1.3E-04	2.5E-05	2.2E-02	3.8E-02	1.1E-03	2.6E-05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E-06	2.0E-06	4.1E-07	2.2E-03	9.8E-04	1.1E-05	3.5E-06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Water, completely softened {RER} water production, completely softened Conseq, S	2.1E-05	4.4E-05	8.5E-06	9.5E-03	1.3E-02	9.3E-04	2.7E-05	1.4E-03	4.2E-01	4.1E-02	1.8E-06

Table F. 13. Scenario 2.2 (Jigger-NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	1.8E+01	8.9E-01	2.4E-05	6.4E-03	4.6E-03	3.4E-02	2.5E+01	8.1E-02	2.6E-01	8.6E-02	4.7E-03
Air Emissions	1.8E+01	8.9E-01	2.4E-05	6.4E-03	4.6E-03	3.4E-02	2.5E+01	8.1E-02	2.6E-01	0	0
Water Emissions	0	0	0	0	1.4E-05	0	0	0	0	8.6E-02	4.7E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	1.2E+00	5.8E-02	1.6E-06	2.4E-04	1.5E-03	2.1E-03	2.4E+00	5.0E-03	1.3E-02	1.0E-02	1.7E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.5E+00	7.3E-02	2.0E-06	3.0E-04	1.9E-03	2.7E-03	3.0E+00	6.2E-03	1.6E-02	1.3E-02	2.1E-06
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07

Table F. 13 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	5.2E-03	2.5E-04	6.9E-09	5.0E-06	9.5E-06	1.0E-05	8.1E-03	2.5E-05	5.2E-05	3.3E-06	1.4E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Jigger_only NF_sludge	0	0	0	0	0	0	0	0	0	6.9E-03	3.9E-06
Jigger_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	7.8E-03	3.8E-04	1.0E-08	2.1E-06	-3.9E-07	3.1E-05	4.8E-02	7.2E-05	7.6E-04	1.9E-04	1.1E-08
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05

Table F. 13 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	5.2E-01	2.5E-02	6.9E-07	1.2E-04	2.2E-04	1.6E-03	9.0E-01	3.8E-03	4.9E-03	5.0E-03	2.5E-06
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	2.5E-02	1.2E-03	3.3E-08	3.2E-06	-2.3E-05	6.9E-05	9.8E-02	1.6E-04	8.1E-04	5.1E-04	5.7E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	5.3E+00	2.6E-01	7.1E-06	7.4E-04	4.4E-04	6.5E-03	3.0E+00	1.5E-02	4.5E-02	8.3E-03	1.4E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08

Table F. 13 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Water, completely softened {RER} water production, completely softened Conseq, S	5.3E-02	2.6E-03	7.0E-08	4.2E-05	1.2E-04	1.0E-04	7.3E-02	2.5E-04	5.8E-04	4.0E-04	8.4E-08

Table F. 14. Scenario 2.2 (Jigger-NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	6.5E-03	2.1E-02	1.4E-03	2.4E+00	3.7E+00	2.8E-01	1.8E-03	8.6E-01	1.1E+00	1.1E-01	6.9E-06
Air Emissions	6.5E-03	6.9E-06	3.0E-05	8.5E-02	2.0E-01	0	0	0	0	0	0
Water Emissions	5.1E-07	2.1E-02	1.3E-03	2.3E+00	3.4E+00	0	0	0	-	-	-7.1E-04
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07
Electricity, high voltage {GLO} market group for Conseq, S	1.1E-04	4.4E-04	8.8E-05	1.8E-01	3.0E-01	5.2E-03	6.8E-05	3.2E-02	5.6E-03	6.7E-04	1.6E-07

Table F. 14 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.4E-04	5.5E-04	1.1E-04	2.2E-01	3.8E-01	6.5E-03	8.5E-05	4.0E-02	7.1E-03	8.4E-04	2.1E-07
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	2.2E-06	4.2E-06	8.0E-07	7.2E-04	1.3E-03	-1.2E-04	9.2E-07	2.6E-04	3.9E-04	3.7E-05	2.6E-09
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Jigger_only NF_sludge	1.6E-09	6.0E-04	1.1E-04	1.8E-02	3.1E-02	0	0	0	0	0	0
Jigger_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	6.4E-06	1.4E-05	3.0E-06	3.9E-02	7.7E-03	6.4E-04	5.2E-05	2.5E-04	3.2E-03	3.2E-04	2.0E-08

Table F. 14 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Reactive Orange 12/Golden Yellow HR	2.6E-14	1.4E-02	5.0E-05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E-09
Soap {GLO} market for Conseq, S	3.0E-04	3.2E-04	4.6E-05	7.7E-02	1.4E-01	9.0E-02	8.0E-05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E-04	-3.6E-07	1.5E-06	2.4E-02	5.1E-02	5.0E-03	4.6E-06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E-08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E-04	3.8E-04	7.7E-05	1.5E-01	2.8E-01	2.3E-02	3.4E-05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	5.3E-04	6.3E-04	1.2E-04	1.6E-01	3.0E-01	9.8E-03	1.2E-04	1.4E-02	1.7E-02	1.8E-03	1.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E-05	2.2E-04	4.4E-05	8.7E-02	1.6E-01	1.4E-02	1.6E-05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	1.0E-05	2.3E-05	4.8E-06	9.4E-03	1.7E-02	1.5E-03	1.7E-06	-3.7E-05	2.4E-03	2.6E-04	1.2E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08

Table F. 14 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Steam, in chemical industry {RER} production Conseq, S	1.6E-03	4.1E-04	1.0E-04	1.7E-01	2.9E-01	1.9E-02	2.1E-04	2.9E-01	3.8E-03	6.8E-04	4.1E-08
Sulfur trioxide {GLO} market for Conseq, S	1.2E-03	6.4E-04	1.4E-04	1.2E-01	5.8E-01	4.7E-03	5.9E-04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E-05	1.3E-04	2.5E-05	2.2E-02	3.8E-02	1.1E-03	2.6E-05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E-06	2.0E-06	4.1E-07	2.2E-03	9.8E-04	1.1E-05	3.5E-06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Water, completely softened {RER} water production, completely softened Conseq, S	2.8E-05	5.8E-05	1.1E-05	1.3E-02	1.7E-02	1.2E-03	3.6E-05	1.8E-03	5.5E-01	5.4E-02	2.4E-06

Table F. 15. Scenario 2.3 (Jigger-UF+NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	1.9E+01	9.2E-01	2.5E-05	6.7E-03	5.1E-03	3.6E-02	2.6E+01	8.5E-02	2.7E-01	9.4E-02	4.7E-03
Air Emissions	1.9E+01	9.2E-01	2.5E-05	6.7E-03	5.1E-03	3.6E-02	2.6E+01	8.5E-02	2.7E-01	0	0
Water Emissions	0	0	0	0	1.5E-05	0	0	0	0	9.4E-02	4.7E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07

Table F. 15 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Citric acid {GLO} market for Conseq, S	2.6E-02	1.3E-03	3.5E-08	3.5E-05	-2.4E-06	7.0E-05	7.4E-02	1.6E-04	5.6E-04	2.7E-04	2.2E-07
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	1.2E+00	5.8E-02	1.6E-06	2.4E-04	1.5E-03	2.1E-03	2.4E+00	5.0E-03	1.3E-02	1.0E-02	1.7E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.4E+00	7.0E-02	1.9E-06	2.8E-04	1.8E-03	2.5E-03	2.9E+00	5.9E-03	1.5E-02	1.2E-02	2.0E-06
Electricity, high voltage {GLO} market group for Conseq, S_UF	2.7E-01	1.3E-02	3.7E-07	5.5E-05	3.5E-04	4.9E-04	5.6E-01	1.1E-03	2.9E-03	2.4E-03	3.9E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	3.9E-03	1.9E-04	5.2E-09	3.8E-06	7.1E-06	7.8E-06	6.1E-03	1.8E-05	3.9E-05	2.5E-06	1.1E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	3.9E-03	1.9E-04	5.2E-09	3.8E-06	7.1E-06	7.8E-06	6.1E-03	1.8E-05	3.9E-05	2.5E-06	1.1E-08
Jigger_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	5.2E-03	2.7E-06
Jigger_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	2.1E-03	1.4E-06
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04

Table F. 15 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	7.2E-03	3.5E-04	9.6E-09	1.9E-06	-3.6E- 07	2.8E-05	4.4E-02	6.7E-05	7.0E-04	1.8E-04	1.0E-08
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E- 04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E- 04	-4.7E- 04	2.2E-04	-1.4E- 02	5.2E-04	-6.7E- 04	1.3E-03	-1.9E- 05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E- 04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	6.7E-01	3.3E-02	9.0E-07	1.6E-04	2.9E-04	2.1E-03	1.2E+00	4.9E-03	6.3E-03	6.5E-03	3.2E-06
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E- 04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	2.3E-02	1.1E-03	3.1E-08	3.0E-06	-2.1E- 05	6.5E-05	9.2E-02	1.5E-04	7.6E-04	4.8E-04	5.3E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	6.3E-02	3.1E-03	8.4E-08	8.1E-06	-5.7E- 05	1.7E-04	2.5E-01	4.0E-04	2.0E-03	1.3E-03	1.4E-07

Table F. 15 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	2.9E-01	1.4E-02	3.9E-07	1.9E-04	2.4E-04	5.7E-04	5.7E-01	1.3E-03	3.4E-03	3.2E-03	6.5E-07
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	5.3E+00	2.6E-01	7.1E-06	7.4E-04	4.4E-04	6.5E-03	3.0E+00	1.5E-02	4.5E-02	8.3E-03	1.4E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E- 01	-1.0E- 02	-2.8E- 07	-5.6E- 06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Water, completely softened {RER} water production, completely softened Conseq, S	6.1E-02	3.0E-03	8.1E-08	4.9E-05	1.3E-04	1.2E-04	8.4E-02	2.9E-04	6.8E-04	4.7E-04	9.8E-08

Table F. 16. Scenario 2.3 (Jigger-UF+NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	7.1E-03	2.1E-02	1.5E-03	2.5E+00	4.1E+00	2.9E-01	2.0E-03	8.8E-01	1.2E+00	1.2E-01	7.5E-06
Air Emissions	7.1E-03	7.3E-06	3.2E-05	9.2E-02	2.2E-01	0	0	0	0	0	0
Water Emissions	5.1E-07	2.1E-02	1.4E-03	2.4E+00	3.8E+00	0	0	0	-	-	-8.0E-04
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	1.1E-05	1.4E-05	2.8E-06	5.1E-03	9.5E-03	9.5E-04	4.1E-06	5.3E-04	1.4E-03	1.4E-04	5.9E-08
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07
Electricity, high voltage {GLO} market group for Conseq, S	1.1E-04	4.4E-04	8.8E-05	1.8E-01	3.0E-01	5.2E-03	6.8E-05	3.2E-02	5.6E-03	6.7E-04	1.6E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.3E-04	5.2E-04	1.1E-04	2.1E-01	3.6E-01	6.2E-03	8.1E-05	3.8E-02	6.7E-03	8.0E-04	2.0E-07
Electricity, high voltage {GLO} market group for Conseq, S_UF	2.5E-05	1.0E-04	2.0E-05	4.1E-02	6.9E-02	1.2E-03	1.6E-05	7.3E-03	1.3E-03	1.5E-04	3.8E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08

Table F. 16 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPe (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	1.7E-06	3.1E-06	6.0E-07	5.4E-04	9.4E-04	-9.3E-05	6.9E-07	1.9E-04	3.0E-04	2.8E-05	2.0E-09
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	1.7E-06	3.1E-06	6.0E-07	5.4E-04	9.4E-04	-9.3E-05	6.9E-07	1.9E-04	3.0E-04	2.8E-05	2.0E-09
Jigger_ only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_ only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Jigger_UF+NF_NF_sludge	6.2E-10	5.4E-04	9.9E-05	1.6E-02	2.8E-02	0	0	0	0	0	0
Jigger_UF+NF_UF_sludge	1.1E-09	6.1E-05	1.1E-05	2.1E-03	3.4E-03	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	5.9E-06	1.3E-05	2.8E-06	3.6E-02	7.1E-03	5.9E-04	4.8E-05	2.3E-04	2.9E-03	2.9E-04	1.9E-08
Reactive Orange 12/Golden Yellow HR	2.6E-14	1.4E-02	5.0E-05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E-09
Soap {GLO} market for Conseq, S	3.0E-04	3.2E-04	4.6E-05	7.7E-02	1.4E-01	9.0E-02	8.0E-05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E-04	-3.6E-07	1.5E-06	2.4E-02	5.1E-02	5.0E-03	4.6E-06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E-08

Table F. 16 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E-04	3.8E-04	7.7E-05	1.5E-01	2.8E-01	2.3E-02	3.4E-05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	6.9E-04	8.2E-04	1.6E-04	2.1E-01	4.0E-01	1.3E-02	1.5E-04	1.8E-02	2.2E-02	2.4E-03	1.7E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E-05	2.2E-04	4.4E-05	8.7E-02	1.6E-01	1.4E-02	1.6E-05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	9.7E-06	2.2E-05	4.5E-06	8.8E-03	1.6E-02	1.4E-03	1.6E-06	-3.5E-05	2.2E-03	2.4E-04	1.1E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	2.6E-05	5.9E-05	1.2E-05	2.4E-02	4.4E-02	3.7E-03	4.3E-06	-9.3E-05	6.0E-03	6.5E-04	2.9E-08
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	3.2E-04	2.4E-04	5.1E-05	6.5E-02	2.0E-01	2.9E-03	1.6E-04	7.3E-03	1.5E-02	1.5E-03	6.9E-08
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	1.6E-03	4.1E-04	1.0E-04	1.7E-01	2.9E-01	1.9E-02	2.1E-04	2.9E-01	3.8E-03	6.8E-04	4.1E-08
Sulfur trioxide {GLO} market for Conseq, S	1.2E-03	6.4E-04	1.4E-04	1.2E-01	5.8E-01	4.7E-03	5.9E-04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E-05	1.3E-04	2.5E-05	2.2E-02	3.8E-02	1.1E-03	2.6E-05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07

Table F. 16 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Tap water {GLO} market group for Conseq, S	1.2E-06	2.0E-06	4.1E-07	2.2E-03	9.8E-04	1.1E-05	3.5E-06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Water, completely softened {RER} water production, completely softened Conseq, S	3.2E-05	6.8E-05	1.3E-05	1.5E-02	2.0E-02	1.4E-03	4.2E-05	2.1E-03	6.4E-01	6.3E-02	2.8E-06

Pad-Steam Dyeing Process Contributions to Mid-Point Impact Categories

Table F. 17. Scenario 3.a (Pad-Baseline) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	3.0E+01	1.49E+00	4.07E-05	8.15E-03	3.96E-03	6.25E-02	3.64E+01	1.47E-01	4.08E-01	1.02E-01	4.69E-03
Air Emissions	3.0E+01	1.49E+00	4.07E-05	8.15E-03	3.95E-03	6.25E-02	3.64E+01	1.47E-01	4.08E-01	0	0
Water Emissions	0	0	0	0	1.08E-05	0	0	0	0	1.02E-01	4.69E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0

Table F. 17 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	8.5E-01	4.2E-02	1.1E-06	1.7E-04	1.1E-03	1.5E-03	1.7E+00	3.5E-03	9.0E-03	7.4E-03	1.2E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Pad_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0

Table F. 17 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.6E+00	7.9E-02	2.2E-06	3.8E-04	6.8E-04	5.0E-03	2.8E+00	1.2E-02	1.5E-02	1.6E-02	7.7E-06
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0

Table F. 17 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	1.8E+01	8.7E-01	2.4E-05	2.5E-03	1.5E-03	2.2E-02	1.0E+01	5.1E-02	1.5E-01	2.8E-02	4.5E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Urea {RER} market for urea Conseq, S	6.1E-01	3.0E-02	8.1E-07	1.3E-04	8.0E-05	9.5E-04	3.0E-01	2.3E-03	5.1E-03	9.5E-04	6.9E-07
Water, completely softened {RER} water production, completely softened Conseq, S	9.7E-02	4.7E-03	1.3E-07	7.8E-05	2.1E-04	1.9E-04	1.3E-01	4.6E-04	1.1E-03	7.4E-04	1.6E-07

Table F. 18. Scenario 3.a (Pad-Baseline) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	1.14E-02	2.24E-02	1.76E-03	2.82E+00	4.67E+00	3.35E-01	2.54E-03	1.58E+00	1.66E+00	1.69E-01	9.35E-06
Air Emissions	1.14E-02	1.16E-05	5.32E-05	1.28E-01	3.06E-01	0	0	0	0	0	0
Water Emissions	5.15E-07	2.23E-02	1.70E-03	2.67E+00	4.23E+00	0	0	0	-	-	-4.79E-04
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07
Electricity, high voltage {GLO} market group for Conseq, S	7.8E-05	3.1E-04	6.3E-05	1.3E-01	2.2E-01	3.7E-03	4.9E-05	2.3E-02	4.0E-03	4.8E-04	1.2E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0

Table F. 18 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Pad_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	2.6E-14	1.4E-02	5.0E-05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E-09
Soap {GLO} market for Conseq, S	3.0E-04	3.2E-04	4.6E-05	7.7E-02	1.4E-01	9.0E-02	8.0E-05	7.1E-03	1.9E-02	2.9E-03	7.7E-07

Table F. 18 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Soda ash, dense {GLO} market for Conseq, S	1.3E- 04	-3.6E- 07	1.5E- 06	2.4E-02	5.1E-02	5.0E- 03	4.6E- 06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E- 08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E- 04	3.8E- 04	7.7E- 05	1.5E-01	2.8E-01	2.3E- 02	3.4E- 05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.7E- 03	2.0E- 03	3.9E- 04	5.0E-01	9.5E-01	3.1E- 02	3.7E- 04	4.4E-02	5.2E-02	5.8E-03	4.0E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E- 05	2.2E- 04	4.4E- 05	8.7E-02	1.6E-01	1.4E- 02	1.6E- 05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.2E- 04	1.5E- 04	3.2E- 05	4.6E-02	1.3E-01	4.2E- 03	9.2E- 05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E- 05	4.0E- 05	9.2E- 06	2.2E-02	4.0E-02	-1.8E- 03	2.2E- 05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	5.2E- 03	1.4E- 03	3.4E- 04	5.6E-01	9.7E-01	6.4E- 02	7.1E- 04	9.7E-01	1.3E-02	2.3E-03	1.4E-07

Table F. 18 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sulfur trioxide {GLO} market for Conseq, S	1.2E- 03	6.4E- 04	1.4E- 04	1.2E-01	5.8E-01	4.7E- 03	5.9E- 04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	4.3E- 05	1.3E- 04	2.5E- 05	2.2E-02	3.8E-02	1.1E- 03	2.6E- 05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E- 06	2.0E- 06	4.1E- 07	2.2E-03	9.8E-04	1.1E- 05	3.5E- 06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Urea {RER} market for urea Conseq, S	3.0E- 04	2.4E- 04	4.9E- 05	4.3E-02	9.0E-02	2.4E- 03	1.0E- 04	5.5E-02	7.6E-02	7.7E-03	3.5E-07
Water, completely softened {RER} water production, completely softened Conseq, S	5.1E- 05	1.1E- 04	2.1E- 05	2.3E-02	3.2E-02	2.3E- 03	6.7E- 05	3.4E-03	1.0E+00	1.0E-01	4.5E-06

Table F. 19. Scenario 3.1 (Pad-UF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	2.97E+01	1.45E+00	3.97E- 05	8.16E- 03	3.71E- 03	5.94E- 02	3.56E+01	1.40E- 01	4.06E- 01	9.02E- 02	4.68E- 03
Air Emissions	2.97E+01	1.45E+00	3.97E- 05	8.16E- 03	3.70E- 03	5.94E- 02	3.56E+01	1.40E- 01	4.06E- 01	0	0
Water Emissions	0	0	0	0	1.00E- 05	0	0	0	0	9.02E- 02	4.68E- 03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E- 06	3.6E- 04	7.6E- 05	3.0E- 03	3.1E+00	7.1E- 03	3.1E- 02	1.2E- 02	1.5E- 06

Table F. 19 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	3.3E-02	1.6E-03	4.5E-08	4.4E-05	-3.1E-06	9.0E-05	9.5E-02	2.1E-04	7.2E-04	3.5E-04	2.9E-07
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	8.5E-01	4.2E-02	1.1E-06	1.7E-04	1.1E-03	1.5E-03	1.7E+00	3.5E-03	9.0E-03	7.4E-03	1.2E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	2.0E-01	9.7E-03	2.7E-07	4.0E-05	2.5E-04	3.6E-04	4.0E-01	8.3E-04	2.1E-03	1.7E-03	2.9E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	6.5E-03	3.2E-04	8.6E-09	6.3E-06	1.2E-05	1.3E-05	1.0E-02	3.1E-05	6.5E-05	4.1E-06	1.8E-08
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04

Table F. 19 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Pad_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_only UF_sludge	0	0	0	0	0	0	0	0	0	2.1E-03	1.4E-06
Pad_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.3E-01	6.2E-03	1.7E-07	3.0E-05	5.4E-05	4.0E-04	2.2E-01	9.3E-04	1.2E-03	1.2E-03	6.0E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07

Table F. 19 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	1.2E-01	6.0E-03	1.6E-07	1.6E-05	-1.1E-04	3.4E-04	4.8E-01	7.8E-04	4.0E-03	2.5E-03	2.8E-07
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	4.6E-01	2.3E-02	6.2E-07	3.1E-04	3.8E-04	8.9E-04	9.1E-01	2.1E-03	5.3E-03	5.0E-03	1.0E-06
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	1.8E+01	8.7E-01	2.4E-05	2.5E-03	1.5E-03	2.2E-02	1.0E+01	5.1E-02	1.5E-01	2.8E-02	4.5E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09
Urea {RER} market for urea Conseq, S	6.1E-01	3.0E-02	8.1E-07	1.3E-04	8.0E-05	9.5E-04	3.0E-01	2.3E-03	5.1E-03	9.5E-04	6.9E-07

Table F. 19 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Water, completely softened {RER} water production, completely softened Conseq, S	3.0E-02	1.5E-03	4.0E-08	2.4E-05	6.6E-05	6.0E-05	4.1E-02	1.4E-04	3.3E-04	2.3E-04	4.8E-08

Table F. 20. Scenario 3.1 (Pad-UF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	1.04E-02	2.06E-02	1.44E-03	2.53E+00	4.21E+00	3.19E-01	2.44E-03	1.55E+00	9.44E-01	9.87E-02	6.13E-06
Air Emissions	1.04E-02	1.04E-05	4.86E-05	1.11E-01	2.84E-01	0	0	0	0	0	0
Water Emissions	5.14E-07	2.06E-02	1.38E-03	2.40E+00	3.81E+00	0	0	0	-	-	-4.43E-04
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	1.4E-05	1.8E-05	3.6E-06	6.5E-03	1.2E-02	1.2E-03	5.3E-06	6.9E-04	1.8E-03	1.8E-04	7.6E-08
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07

Table F. 20 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Electricity, high voltage {GLO} market group for Conseq, S	7.8E-05	3.1E-04	6.3E-05	1.3E-01	2.2E-01	3.7E-03	4.9E-05	2.3E-02	4.0E-03	4.8E-04	1.2E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Electricity, high voltage {GLO} market group for Conseq, S_UF	1.8E-05	7.3E-05	1.5E-05	2.9E-02	5.0E-02	8.6E-04	1.1E-05	5.3E-03	9.4E-04	1.1E-04	2.7E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	2.8E-06	5.2E-06	1.0E-06	8.9E-04	1.6E-03	-1.6E-04	1.1E-06	3.2E-04	4.9E-04	4.6E-05	3.3E-09
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Pad_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_only UF_sludge	1.1E-09	6.1E-05	1.1E-05	2.1E-03	3.4E-03	0	0	0	0	0	0
Pad_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0

Table F. 20 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Reactive Orange 12/Golden Yellow HR	2.6E- 14	1.4E- 02	5.0E- 05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E- 09
Soap {GLO} market for Conseq, S	3.0E- 04	3.2E- 04	4.6E- 05	7.7E-02	1.4E-01	9.0E- 02	8.0E- 05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E- 04	-3.6E- 07	1.5E- 06	2.4E-02	5.1E-02	5.0E- 03	4.6E- 06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E- 08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E- 04	3.8E- 04	7.7E- 05	1.5E-01	2.8E-01	2.3E- 02	3.4E- 05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	1.3E- 04	1.5E- 04	3.1E- 05	3.9E-02	7.5E-02	2.4E- 03	2.9E- 05	3.5E-03	4.1E-03	4.5E-04	3.1E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E- 05	2.2E- 04	4.4E- 05	8.7E-02	1.6E-01	1.4E- 02	1.6E- 05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	0	0	0	0	0	0	0	0	0
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	5.1E- 05	1.1E- 04	2.3E- 05	4.6E-02	8.5E-02	7.1E- 03	8.4E- 06	-1.8E-04	1.2E-02	1.3E-03	5.6E-08
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	5.1E- 04	3.8E- 04	8.1E- 05	1.0E-01	3.2E-01	4.6E- 03	2.6E- 04	1.2E-02	2.4E-02	2.4E-03	1.1E-07

Table F. 20 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	5.2E-03	1.4E-03	3.4E-04	5.6E-01	9.7E-01	6.4E-02	7.1E-04	9.7E-01	1.3E-02	2.3E-03	1.4E-07
Sulfur trioxide {GLO} market for Conseq, S	1.2E-03	6.4E-04	1.4E-04	1.2E-01	5.8E-01	4.7E-03	5.9E-04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E-05	1.3E-04	2.5E-05	2.2E-02	3.8E-02	1.1E-03	2.6E-05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E-06	2.0E-06	4.1E-07	2.2E-03	9.8E-04	1.1E-05	3.5E-06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Urea {RER} market for urea Conseq, S	3.0E-04	2.4E-04	4.9E-05	4.3E-02	9.0E-02	2.4E-03	1.0E-04	5.5E-02	7.6E-02	7.7E-03	3.5E-07
Water, completely softened {RER} water production, completely softened Conseq, S	1.6E-05	3.3E-05	6.4E-06	7.2E-03	9.9E-03	7.0E-04	2.1E-05	1.1E-03	3.2E-01	3.1E-02	1.4E-06

Table F. 21. Scenario 3.2 (Pad-NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	3.06E+01	1.50E+00	4.09E-05	8.11E-03	4.90E-03	6.14E-02	3.71E+01	1.44E-01	4.12E-01	1.01E-01	4.69E-03

Table F. 21 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Air Emissions	3.06E+01	1.50E+00	4.09E-05	8.11E-03	4.88E-03	6.14E-02	3.71E+01	1.44E-01	4.12E-01	0	0
Water Emissions	0	0	0	0	1.38E-05	0	0	0	0	1.01E-01	4.69E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	8.5E-01	4.2E-02	1.1E-06	1.7E-04	1.1E-03	1.5E-03	1.7E+00	3.5E-03	9.0E-03	7.4E-03	1.2E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.2E+00	5.8E-02	1.6E-06	2.4E-04	1.5E-03	2.1E-03	2.4E+00	4.9E-03	1.3E-02	1.0E-02	1.7E-06
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	3.9E-03	1.9E-04	5.2E-09	3.8E-06	7.1E-06	7.8E-06	6.1E-03	1.8E-05	3.9E-05	2.5E-06	1.1E-08

Table F. 21 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOPP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S UF	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Pad_only NF_sludge	0	0	0	0	0	0	0	0	0	6.9E-03	3.9E-06
Pad_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	5.9E-03	2.9E-04	7.8E-09	1.6E-06	-3.0E-07	2.3E-05	3.6E-02	5.4E-05	5.8E-04	1.5E-04	8.4E-09
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	5.9E-01	2.9E-02	7.8E-07	1.4E-04	2.5E-04	1.8E-03	1.0E+00	4.3E-03	5.5E-03	5.6E-03	2.8E-06

Table F. 21 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	1.9E-02	9.2E-04	2.5E-08	2.4E-06	-1.7E-05	5.2E-05	7.3E-02	1.2E-04	6.1E-04	3.8E-04	4.3E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07
Steam, in chemical industry {RER} production Conseq, S	1.8E+01	8.7E-01	2.4E-05	2.5E-03	1.5E-03	2.2E-02	1.0E+01	5.1E-02	1.5E-01	2.8E-02	4.5E-06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E-07	1.1E-04	2.9E-04	1.8E-03	2.5E+00	4.3E-03	3.9E-02	5.0E-03	7.6E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E-07	-5.6E-06	2.6E-05	1.3E-04	1.1E+00	3.0E-04	1.9E-02	2.2E-04	4.3E-08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E-09	2.1E-06	1.5E-06	8.0E-06	5.3E-03	1.9E-05	4.0E-05	2.4E-05	5.9E-09

Table F. 21 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Urea {RER} market for urea Conseq, S	6.1E-01	3.0E-02	8.1E-07	1.3E-04	8.0E-05	9.5E-04	3.0E-01	2.3E-03	5.1E-03	9.5E-04	6.9E-07
Water, completely softened {RER} water production, completely softened Conseq, S	4.3E-02	2.1E-03	5.8E-08	3.5E-05	9.5E-05	8.6E-05	6.0E-02	2.0E-04	4.8E-04	3.3E-04	6.9E-08

Table F. 22. Scenario 3.2 (Pad-NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	1.04E-02	2.16E-02	1.62E-03	2.71E+00	4.36E+00	3.21E-01	2.38E-03	1.58E+00	1.07E+00	1.11E-01	6.78E-06
Air Emissions	1.04E-02	1.06E-05	4.88E-05	1.13E-01	2.78E-01	0	0	0	0	0	0
Water Emissions	5.14E-07	2.15E-02	1.56E-03	2.58E+00	3.96E+00	0	0	0	-	-	-6.17E-04
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0

Table F. 22 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPe (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07
Electricity, high voltage {GLO} market group for Conseq, S	7.8E-05	3.1E-04	6.3E-05	1.3E-01	2.2E-01	3.7E-03	4.9E-05	2.3E-02	4.0E-03	4.8E-04	1.2E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.1E-04	4.3E-04	8.7E-05	1.7E-01	3.0E-01	5.1E-03	6.7E-05	3.1E-02	5.6E-03	6.6E-04	1.6E-07
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	1.7E-06	3.1E-06	6.0E-07	5.4E-04	9.4E-04	-9.3E-05	6.9E-07	1.9E-04	3.0E-04	2.8E-05	2.0E-09
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E-04	-1.6E-05	5.8E-07	4.6E-01	3.6E-02	1.8E-03	-2.3E-04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E-04	5.3E-04	7.3E-05	1.4E-01	1.9E-01	6.9E-02	8.4E-05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Pad_only NF_sludge	1.6E-09	6.0E-04	1.1E-04	1.8E-02	3.1E-02	0	0	0	0	0	0
Pad_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	0	0

Table F. 22 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Pad_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	4.8E- 06	1.1E- 05	2.3E- 06	2.9E-02	5.8E-03	4.8E- 04	3.9E- 05	1.9E-04	2.4E-03	2.4E-04	1.5E-08
Reactive Orange 12/Golden Yellow HR	2.6E- 14	1.4E- 02	5.0E- 05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E- 09
Soap {GLO} market for Conseq, S	3.0E- 04	3.2E- 04	4.6E- 05	7.7E-02	1.4E-01	9.0E- 02	8.0E- 05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E- 04	-3.6E- 07	1.5E- 06	2.4E-02	5.1E-02	5.0E- 03	4.6E- 06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E- 08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E- 04	3.8E- 04	7.7E- 05	1.5E-01	2.8E-01	2.3E- 02	3.4E- 05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	6.0E- 04	7.1E- 04	1.4E- 04	1.8E-01	3.4E-01	1.1E- 02	1.3E- 04	1.6E-02	1.9E-02	2.1E-03	1.4E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E- 05	2.2E- 04	4.4E- 05	8.7E-02	1.6E-01	1.4E- 02	1.6E- 05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	7.8E- 06	1.8E- 05	3.6E- 06	7.1E-03	1.3E-02	1.1E- 03	1.3E- 06	-2.8E-05	1.8E-03	1.9E-04	8.6E-09
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	0	0	0	0	0	0	0	0	0	0

Table F. 22 (cont'd)

Processes	TE/TP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	0	0	0	0	0	0	0	0	0	0
Sodium nitrite {GLO} market for Conseq, S	2.2E- 04	1.5E- 04	3.2E- 05	4.6E-02	1.3E-01	4.2E- 03	9.2E- 05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E- 05	4.0E- 05	9.2E- 06	2.2E-02	4.0E-02	-1.8E- 03	2.2E- 05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	5.2E- 03	1.4E- 03	3.4E- 04	5.6E-01	9.7E-01	6.4E- 02	7.1E- 04	9.7E-01	1.3E-02	2.3E-03	1.4E-07
Sulfur trioxide {GLO} market for Conseq, S	1.2E- 03	6.4E- 04	1.4E- 04	1.2E-01	5.8E-01	4.7E- 03	5.9E- 04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E- 05	1.3E- 04	2.5E- 05	2.2E-02	3.8E-02	1.1E- 03	2.6E- 05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E- 06	2.0E- 06	4.1E- 07	2.2E-03	9.8E-04	1.1E- 05	3.5E- 06	8.5E-05	1.7E-03	3.8E-04	8.2E-08
Urea {RER} market for urea Conseq, S	3.0E- 04	2.4E- 04	4.9E- 05	4.3E-02	9.0E-02	2.4E- 03	1.0E- 04	5.5E-02	7.6E-02	7.7E-03	3.5E-07
Water, completely softened {RER} water production, completely softened Conseq, S	2.3E- 05	4.8E- 05	9.3E- 06	1.0E-02	1.4E-02	1.0E- 03	3.0E- 05	1.5E-03	4.6E-01	4.5E-02	2.0E-06

Table F. 23. Scenario 3.3 (Pad-UF+NF) Process Contributions to Mid-point Impact Categories (HGWP – MEP)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Total	3.12E+01	1.53E+00	4.17E-05	8.38E-03	5.39E-03	6.28E-02	3.84E+01	1.48E-01	4.20E-01	1.08E-01	4.69E-03
Air Emissions	3.12E+01	1.53E+00	4.17E-05	8.38E-03	5.37E-03	6.28E-02	3.84E+01	1.48E-01	4.20E-01	0	0
Water Emissions	0	0	0	0	1.53E-05	0	0	0	0	1.08E-01	4.69E-03
Alpha-naphthol {RoW} production Conseq, S	1.2E+00	5.9E-02	1.6E-06	3.6E-04	7.6E-05	3.0E-03	3.1E+00	7.1E-03	3.1E-02	1.2E-02	1.5E-06
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	2.9E+00	1.4E-01	3.9E-06	3.5E-04	1.3E-04	2.3E-03	5.2E-01	5.4E-03	7.1E-03	1.2E-03	2.3E-07
Citric acid {GLO} market for Conseq, S	2.1E-02	1.0E-03	2.9E-08	2.8E-05	-2.0E-06	5.7E-05	6.1E-02	1.3E-04	4.6E-04	2.2E-04	1.8E-07
Cyanuric chloride {GLO} market for Conseq, S	8.9E-01	4.3E-02	1.2E-06	2.8E-04	5.4E-04	1.1E-03	3.8E-01	2.6E-03	2.0E-03	1.1E-03	9.8E-07
Electricity, high voltage {GLO} market group for Conseq, S	8.5E-01	4.2E-02	1.1E-06	1.7E-04	1.1E-03	1.5E-03	1.7E+00	3.5E-03	9.0E-03	7.4E-03	1.2E-06
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.2E+00	5.8E-02	1.6E-06	2.4E-04	1.5E-03	2.1E-03	2.4E+00	4.9E-03	1.3E-02	1.0E-02	1.7E-06
Electricity, high voltage {GLO} market group for Conseq, S_UF	2.1E-01	1.0E-02	2.8E-07	4.2E-05	2.7E-04	3.7E-04	4.2E-01	8.7E-04	2.2E-03	1.8E-03	3.0E-07

Table F. 23 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	1.1E-01	5.4E-03	1.5E-07	1.1E-04	2.0E-04	2.2E-04	1.7E-01	5.2E-04	1.1E-03	7.0E-05	3.0E-07
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	2.6E-03	1.3E-04	3.5E-09	2.5E-06	4.7E-06	5.2E-06	4.1E-03	1.2E-05	2.6E-05	1.6E-06	7.2E-09
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	3.9E-03	1.9E-04	5.2E-09	3.8E-06	7.1E-06	7.8E-06	6.1E-03	1.8E-05	3.9E-05	2.5E-06	1.1E-08
Meta-phenylene diamine {GLO} market for Conseq, S	6.8E-01	3.3E-02	9.1E-07	1.3E-03	2.1E-05	7.9E-04	4.3E-01	1.9E-03	6.2E-03	9.7E-04	2.9E-04
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.1E+00	5.5E-02	1.5E-06	9.4E-04	2.3E-04	2.3E-03	9.7E-01	6.2E-03	1.1E-02	5.7E-04	2.7E-05
Pad_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_NF_sludge	0	0	0	0	0	0	0	0	0	5.2E-03	2.7E-06
Pad_UF+NF_UF_sludge	0	0	0	0	0	0	0	0	0	2.1E-03	1.4E-06
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	5.4E-03	2.6E-04	7.2E-09	1.5E-06	-2.7E-07	2.1E-05	3.3E-02	5.0E-05	5.3E-04	1.3E-04	7.7E-09
Reactive Orange 12/Golden Yellow HR	1.8E-01	8.7E-03	2.4E-07	0	0	0	0	0	0	0	4.3E-03

Table F. 23 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Soap {GLO} market for Conseq, S	8.6E-01	4.2E-02	1.1E-06	1.4E-03	-2.2E-04	1.4E-03	9.5E-01	3.4E-03	1.1E-02	2.8E-03	3.4E-05
Soda ash, dense {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	-1.1E-04	-4.7E-04	2.2E-04	-1.4E-02	5.2E-04	-6.7E-04	1.3E-03	-1.9E-05
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	4.1E-01	2.0E-02	5.5E-07	5.6E-05	-3.6E-04	1.2E-03	1.6E+00	2.8E-03	1.3E-02	8.2E-03	9.1E-07
Sodium chloride, powder {GLO} market for Conseq, S	6.9E-01	3.4E-02	9.3E-07	1.6E-04	2.9E-04	2.2E-03	1.2E+00	5.1E-03	6.5E-03	6.7E-03	3.3E-06
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	3.0E-05	-2.1E-04	6.4E-04	9.1E-01	1.5E-03	7.5E-03	4.7E-03	5.3E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	1.7E-02	8.5E-04	2.3E-08	2.3E-06	-1.6E-05	4.8E-05	6.8E-02	1.1E-04	5.6E-04	3.6E-04	4.0E-08
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	5.3E-02	2.6E-03	7.1E-08	6.9E-06	-4.8E-05	1.5E-04	2.1E-01	3.4E-04	1.7E-03	1.1E-03	1.2E-07
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	2.5E-01	1.2E-02	3.3E-07	1.6E-04	2.0E-04	4.7E-04	4.8E-01	1.1E-03	2.8E-03	2.6E-03	5.5E-07
Sodium nitrite {GLO} market for Conseq, S	2.3E-01	1.1E-02	3.1E-07	4.2E-05	8.8E-05	5.1E-04	4.8E-01	1.2E-03	4.0E-03	2.5E-03	1.4E-06
Sodium sulfate, anhydrite {RER} market for Conseq, S	2.6E-01	1.3E-02	3.5E-07	4.7E-05	8.6E-05	3.4E-04	1.4E-01	8.0E-04	1.3E-03	9.6E-04	1.5E-07

Table F. 23 (cont'd)

Processes	HGWP (Pt)	TGWP (Pt)	FGWP (Pt)	ODP (Pt)	IRP (Pt)	HOFP (Pt)	FPMF (Pt)	TOFP (Pt)	TAP (Pt)	FEP (Pt)	MEP (Pt)
Steam, in chemical industry {RER} production Conseq, S	1.8E+01	8.7E-01	2.4E- 05	2.5E- 03	1.5E- 03	2.2E- 02	1.0E+01	5.1E- 02	1.5E- 01	2.8E- 02	4.5E- 06
Sulfur trioxide {GLO} market for Conseq, S	4.0E-01	1.9E-02	5.3E- 07	1.1E- 04	2.9E- 04	1.8E- 03	2.5E+00	4.3E- 03	3.9E- 02	5.0E- 03	7.6E- 07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-2.1E-01	-1.0E-02	-2.8E- 07	-5.6E- 06	2.6E- 05	1.3E- 04	1.1E+00	3.0E- 04	1.9E- 02	2.2E- 04	4.3E- 08
Tap water {GLO} market group for Conseq, S	3.6E-03	1.8E-04	4.8E- 09	2.1E- 06	1.5E- 06	8.0E- 06	5.3E-03	1.9E- 05	4.0E- 05	2.4E- 05	5.9E- 09
Urea {RER} market for urea Conseq, S	6.1E-01	3.0E-02	8.1E- 07	1.3E- 04	8.0E- 05	9.5E- 04	3.0E-01	2.3E- 03	5.1E- 03	9.5E- 04	6.9E- 07
Water, completely softened {RER} water production, completely softened Conseq, S	4.8E-02	2.3E-03	6.4E- 08	3.8E- 05	1.0E- 04	9.5E- 05	6.6E-02	2.2E- 04	5.3E- 04	3.6E- 04	7.7E- 08

Table F. 24. Scenario 3.3 (Pad-UF+NF) Process Contributions to Mid-point Impact Categories (TETP – AWCP)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Total	1.09E- 02	2.21E- 02	1.72E- 03	2.86E+00	4.69E+00	3.30E- 01	2.56E- 03	1.59E+00	1.14E+00	1.18E-01	7.18E- 06
Air Emissions	1.09E- 02	1.10E- 05	5.07E- 05	1.19E-01	2.97E-01	0	0	0	0	0	0
Water Emissions	5.14E- 07	2.20E- 02	1.66E- 03	2.72E+00	4.27E+00	0	0	0	- 6.48E+01	- 7.21E+00	-6.98E- 04

Table F. 24 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Alpha-naphthol {RoW} production Conseq, S	6.2E-04	8.5E-04	1.7E-04	2.6E-01	5.0E-01	2.7E-02	1.6E-04	1.2E-01	8.5E-02	8.9E-03	4.6E-07
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	5.3E-04	4.3E-04	8.9E-05	5.8E-02	1.4E-01	2.7E-03	3.1E-04	1.7E-01	7.6E-02	8.5E-03	3.6E-07
Citric acid {GLO} market for Conseq, S	9.0E-06	1.2E-05	2.3E-06	4.2E-03	7.8E-03	7.8E-04	3.4E-06	4.4E-04	1.1E-03	1.1E-04	4.9E-08
Cyanuric chloride {GLO} market for Conseq, S	1.3E-04	2.0E-04	4.0E-05	7.7E-02	7.1E-02	-5.1E-03	4.7E-05	4.0E-02	1.6E-02	1.5E-03	1.1E-07
Electricity, high voltage {GLO} market group for Conseq, S	7.8E-05	3.1E-04	6.3E-05	1.3E-01	2.2E-01	3.7E-03	4.9E-05	2.3E-02	4.0E-03	4.8E-04	1.2E-07
Electricity, high voltage {GLO} market group for Conseq, S_NF	1.1E-04	4.4E-04	8.8E-05	1.8E-01	3.0E-01	5.2E-03	6.8E-05	3.2E-02	5.6E-03	6.7E-04	1.6E-07
Electricity, high voltage {GLO} market group for Conseq, S_UF	1.9E-05	7.6E-05	1.5E-05	3.1E-02	5.3E-02	9.1E-04	1.2E-05	5.5E-03	9.8E-04	1.2E-04	2.9E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	4.7E-05	8.9E-05	1.7E-05	1.5E-02	2.7E-02	-2.6E-03	2.0E-05	5.5E-03	8.4E-03	7.8E-04	5.6E-08
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	1.1E-06	2.1E-06	4.0E-07	3.6E-04	6.3E-04	-6.2E-05	4.6E-07	1.3E-04	2.0E-04	1.8E-05	1.3E-09
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	1.7E-06	3.1E-06	6.0E-07	5.4E-04	9.4E-04	-9.3E-05	6.9E-07	1.9E-04	3.0E-04	2.8E-05	2.0E-09

Table F. 24 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Meta-phenylene diamine {GLO} market for Conseq, S	2.7E- 04	-1.6E- 05	5.8E- 07	4.6E-01	3.6E-02	1.8E- 03	-2.3E- 04	3.3E-02	9.2E-03	9.1E-04	7.8E-08
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	3.2E- 04	5.3E- 04	7.3E- 05	1.4E-01	1.9E-01	6.9E- 02	8.4E- 05	7.0E-02	4.6E-02	5.2E-03	8.7E-07
Pad_only NF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_only UF_sludge	0	0	0	0	0	0	0	0	0	0	0
Pad_UF+NF_NF_sludge	6.2E- 10	5.4E- 04	9.9E- 05	1.6E-02	2.8E-02	0	0	0	0	0	0
Pad_UF+NF_UF_sludge	1.1E- 09	6.1E- 05	1.1E- 05	2.1E-03	3.4E-03	0	0	0	0	0	0
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	4.5E- 06	9.9E- 06	2.1E- 06	2.7E-02	5.3E-03	4.4E- 04	3.6E- 05	1.7E-04	2.2E-03	2.2E-04	1.4E-08
Reactive Orange 12/Golden Yellow HR	2.6E- 14	1.4E- 02	5.0E- 05	0	0	0	0	0	-1.1E-03	-1.1E-04	-5.1E- 09
Soap {GLO} market for Conseq, S	3.0E- 04	3.2E- 04	4.6E- 05	7.7E-02	1.4E-01	9.0E- 02	8.0E- 05	7.1E-03	1.9E-02	2.9E-03	7.7E-07
Soda ash, dense {GLO} market for Conseq, S	1.3E- 04	-3.6E- 07	1.5E- 06	2.4E-02	5.1E-02	5.0E- 03	4.6E- 06	8.2E-03	-2.8E-03	-1.4E-04	-2.1E- 08
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.0E- 04	3.8E- 04	7.7E- 05	1.5E-01	2.8E-01	2.3E- 02	3.4E- 05	2.5E-04	3.8E-02	4.1E-03	1.8E-07
Sodium chloride, powder {GLO} market for Conseq, S	7.1E- 04	8.4E- 04	1.7E- 04	2.1E-01	4.1E-01	1.3E- 02	1.6E- 04	1.9E-02	2.2E-02	2.5E-03	1.7E-07

Table F. 24 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPe (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	9.6E-05	2.2E-04	4.4E-05	8.7E-02	1.6E-01	1.4E-02	1.6E-05	-3.4E-04	2.2E-02	2.4E-03	1.1E-07
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	7.2E-06	1.6E-05	3.3E-06	6.5E-03	1.2E-02	1.0E-03	1.2E-06	-2.6E-05	1.6E-03	1.8E-04	8.0E-09
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	2.2E-05	5.0E-05	1.0E-05	2.0E-02	3.7E-02	3.1E-03	3.7E-06	-7.8E-05	5.0E-03	5.5E-04	2.4E-08
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	2.7E-04	2.0E-04	4.3E-05	5.4E-02	1.7E-01	2.4E-03	1.4E-04	6.1E-03	1.3E-02	1.3E-03	5.7E-08
Sodium nitrite {GLO} market for Conseq, S	2.2E-04	1.5E-04	3.2E-05	4.6E-02	1.3E-01	4.2E-03	9.2E-05	7.2E-03	1.7E-02	1.7E-03	7.5E-08
Sodium sulfate, anhydrite {RER} market for Conseq, S	8.6E-05	4.0E-05	9.2E-06	2.2E-02	4.0E-02	-1.8E-03	2.2E-05	1.4E-02	1.2E-03	1.8E-04	1.1E-08
Steam, in chemical industry {RER} production Conseq, S	5.2E-03	1.4E-03	3.4E-04	5.6E-01	9.7E-01	6.4E-02	7.1E-04	9.7E-01	1.3E-02	2.3E-03	1.4E-07
Sulfur trioxide {GLO} market for Conseq, S	1.2E-03	6.4E-04	1.4E-04	1.2E-01	5.8E-01	4.7E-03	5.9E-04	1.4E-02	1.1E-01	1.0E-02	4.7E-07
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-4.3E-05	1.3E-04	2.5E-05	2.2E-02	3.8E-02	1.1E-03	2.6E-05	-9.8E-03	5.1E-02	5.0E-03	2.2E-07
Tap water {GLO} market group for Conseq, S	1.2E-06	2.0E-06	4.1E-07	2.2E-03	9.8E-04	1.1E-05	3.5E-06	8.5E-05	1.7E-03	3.8E-04	8.2E-08

Table F. 24 (cont'd)

Processes	TETP (Pt)	FETP (Pt)	METP (Pt)	HTPc (Pt)	HTPnc (Pt)	LOP (Pt)	SOP (Pt)	FFP (Pt)	HWCP (Pt)	TWCP (Pt)	AWCP (Pt)
Urea {RER} market for urea Conseq, S	3.0E- 04	2.4E- 04	4.9E- 05	4.3E-02	9.0E-02	2.4E- 03	1.0E- 04	5.5E-02	7.6E-02	7.7E-03	3.5E-07
Water, completely softened {RER} water production, completely softened Conseq, S	2.5E- 05	5.3E- 05	1.0E- 05	1.1E-02	1.6E-02	1.1E- 03	3.3E- 05	1.7E-03	5.0E-01	4.9E-02	2.2E-06

G. Process Contributions to End-Point Impact Categories

Jet Dyeing Process Contributions to End-Point Impact Categories

Table G. 1. Jet Dyeing Scenarios Process Contributions to Human Health End-point Impact Category

Processes	Sc.1.a	Sc. 1.1	Sc. 1.2	Sc. 1.3
Total	74.9	73.9	76.7	81.1
Air Emissions	65	65.6	68.1	71.7
Water Emissions	-58.6	-61.5	-79.3	-90.8
Alpha-naphthol {RoW} production Conseq, S	5.1E+00	5.1E+00	5.1E+00	5.1E+00
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	3.7E+00	3.7E+00	3.7E+00	3.7E+00
Citric acid {GLO} market for Conseq, S	0	2.8E-01	0	1.7E-01
Cyanuric chloride {GLO} market for Conseq, S	1.4E+00	1.4E+00	1.4E+00	1.4E+00
Electricity, high voltage {GLO} market group for Conseq, S	7.0E+00	7.0E+00	7.0E+00	7.0E+00
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	6.9E+00	7.1E+00
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	1.3E+00	0	1.4E+00
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	3.3E-01	3.3E-01	3.3E-01	3.3E-01
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	2.4E-02	1.6E-02
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	3.5E-02	0	2.0E-02
Jet_only NF_sludge	0	0	4.9E-02	0
Jet_only UF_sludge	0	5.5E-03	0	0
Jet_UF+NF_NF_sludge	0	0	0	4.4E-02
Jet_UF+NF_UF_sludge	0	0	0	5.5E-03
Meta-phenylene diamine {GLO} market for Conseq, S	1.6E+00	1.6E+00	1.6E+00	1.6E+00
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	2.5E+00	2.5E+00	2.5E+00	2.5E+00
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	1.6E-01	1.5E-01
Reactive Orange 12/Golden Yellow HR	1.8E-01	1.8E-01	1.8E-01	1.8E-01
Soap {GLO} market for Conseq, S	2.1E+00	2.1E+00	2.1E+00	2.1E+00
Soda ash, dense {GLO} market for Conseq, S	2.9E-01	2.9E-01	2.9E-01	2.9E-01
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.5E+00	2.5E+00	2.5E+00	2.5E+00

Table G. 1 (cont'd)

Processes	Sc.1.a	Sc. 1.1	Sc. 1.2	Sc. 1.3
Sodium chloride, powder {GLO} market for Conseq, S	5.9E+00	4.3E-01	1.9E+00	2.2E+00
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	1.4E+00	1.4E+00	1.4E+00	1.4E+00
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	2.3E-01	2.1E-01
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	1.3E+00	0	5.6E-01
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	3.3E+00	0	1.7E+00
Sodium nitrite {GLO} market for Conseq, S	9.0E-01	9.0E-01	9.0E-01	9.0E-01
Sodium sulfate, anhydrite {RER} market for Conseq, S	4.7E-01	4.7E-01	4.7E-01	4.7E-01
Steam, in chemical industry {RER} production Conseq, S	2.6E+01	2.6E+01	2.6E+01	2.6E+01
Sulfur trioxide {GLO} market for Conseq, S	3.7E+00	3.7E+00	3.7E+00	3.7E+00
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	9.6E-01	9.6E-01	9.6E-01	9.6E-01
Tap water {GLO} market group for Conseq, S	1.4E-02	1.4E-02	1.4E-02	1.4E-02
Water, completely softened {RER} water production, completely softened Conseq, S	2.6E+00	8.0E-01	1.0E+00	1.1E+00

Table G. 2. Jet Dyeing Scenarios Process Contributions to Ecosystems End-point Impact Category

Processes	Sc.1.a	Sc. 1.1	Sc. 1.2	Sc. 1.3
Total	2.72	2.56	2.64	2.75
Air Emissions	1.98	1.98	2.04	2.11
Water Emissions	-7.21	-7.44	-9.37	-10.7
Alpha-naphthol {RoW} production Conseq, S	1.5E-01	1.5E-01	1.5E-01	1.5E-01
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	1.7E-01	1.7E-01	1.7E-01	1.7E-01
Citric acid {GLO} market for Conseq, S	0	8.1E-03	0	5.0E-03
Cyanuric chloride {GLO} market for Conseq, S	4.6E-02	4.6E-02	4.6E-02	4.6E-02
Electricity, high voltage {GLO} market group for Conseq, S	1.6E-01	1.6E-01	1.6E-01	1.6E-01
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	1.6E-01	1.6E-01
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	3.0E-02	0	3.1E-02
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	5.4E-03	5.4E-03	5.4E-03	5.4E-03
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	3.8E-04	2.5E-04

Table G. 2 (cont'd)

Processes	Sc.1.a	Sc. 1.1	Sc. 1.2	Sc. 1.3
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	5.7E-04	0	3.2E-04
Jet_only NF_sludge	0	0	7.7E-03	0
Jet_only UF_sludge	0	2.1E-03	0	0
Jet_UF+NF_NF_sludge	0	0	0	5.9E-03
Jet_UF+NF_UF_sludge	0	0	0	2.1E-03
Meta-phenylene diamine {GLO} market for Conseq, S	4.6E-02	4.6E-02	4.6E-02	4.6E-02
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.5E-01	1.5E-01	1.5E-01	1.5E-01
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	3.6E-03	3.3E-03
Reactive Orange 12/Golden Yellow HR	2.7E-02	2.7E-02	2.7E-02	2.7E-02
Soap {GLO} market for Conseq, S	1.5E-01	1.5E-01	1.5E-01	1.5E-01
Soda ash, dense {GLO} market for Conseq, S	1.8E-02	1.8E-02	1.8E-02	1.8E-02
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	7.2E-02	7.2E-02	7.2E-02	7.2E-02
Sodium chloride, powder {GLO} market for Conseq, S	1.6E-01	1.2E-02	5.2E-02	6.1E-02
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	4.1E-02	4.1E-02	4.1E-02	4.1E-02
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	6.7E-03	6.2E-03
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	3.9E-02	0	1.6E-02
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	7.9E-02	0	4.1E-02
Sodium nitrite {GLO} market for Conseq, S	2.5E-02	2.5E-02	2.5E-02	2.5E-02
Sodium sulfate, anhydrite {RER} market for Conseq, S	1.4E-02	1.4E-02	1.4E-02	1.4E-02
Steam, in chemical industry {RER} production Conseq, S	1.1E+00	1.1E+00	1.1E+00	1.1E+00
Sulfur trioxide {GLO} market for Conseq, S	8.5E-02	8.5E-02	8.5E-02	8.5E-02
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	1.6E-02	1.6E-02	1.6E-02	1.6E-02
Tap water {GLO} market group for Conseq, S	6.5E-04	6.5E-04	6.5E-04	6.5E-04
Water, completely softened {RER} water production, completely softened Conseq, S	2.2E-01	6.7E-02	8.4E-02	9.2E-02

Table G. 3. Jet Dyeing Scenarios Process Contributions to Resources End-point Impact Category

Processes	Sc.1.a	Sc. 1.1	Sc. 1.2	Sc. 1.3
Total	1.46	1.45	1.48	1.51
Air Emissions	0	0	0	0
Water Emissions	0	0	0	0
Alpha-naphthol {RoW} production Conseq, S	1.2E-01	1.2E-01	1.2E-01	1.2E-01
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	1.7E-01	1.7E-01	1.7E-01	1.7E-01
Citric acid {GLO} market for Conseq, S	0	1.3E-03	0	7.9E-04
Cyanuric chloride {GLO} market for Conseq, S	4.0E-02	4.0E-02	4.0E-02	4.0E-02
Electricity, high voltage {GLO} market group for Conseq, S	5.5E-02	5.5E-02	5.5E-02	5.5E-02
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	5.4E-02	5.5E-02
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	1.0E-02	0	1.1E-02
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	5.5E-03	5.5E-03	5.5E-03	5.5E-03
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	3.9E-04	2.6E-04
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	5.8E-04	0	3.2E-04
Jet_only NF_sludge	0	0	0	0
Jet_only UF_sludge	0	0	0	0
Jet_UF+NF_NF_sludge	0	0	0	0
Jet_UF+NF_UF_sludge	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	3.2E-02	3.2E-02	3.2E-02	3.2E-02
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	7.0E-02	7.0E-02	7.0E-02	7.0E-02
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	4.5E-04	4.2E-04
Reactive Orange 12/Golden Yellow HR	0	0	0	0
Soap {GLO} market for Conseq, S	7.2E-03	7.2E-03	7.2E-03	7.2E-03
Soda ash, dense {GLO} market for Conseq, S	8.2E-03	8.2E-03	8.2E-03	8.2E-03
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.9E-04	2.9E-04	2.9E-04	2.9E-04

Table G. 3 (cont'd)

Processes	Sc.1.a	Sc. 1.1	Sc. 1.2	Sc. 1.3
Sodium chloride, powder {GLO} market for Conseq, S	4.5E-02	3.3E-03	1.4E-02	1.7E-02
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	-3.3E-04	-3.3E-04	-3.3E-04	-3.3E-04
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	-5.3E-05	-4.9E-05
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	-3.1E-04	0	-1.3E-04
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	2.2E-02	0	1.1E-02
Sodium nitrite {GLO} market for Conseq, S	7.3E-03	7.3E-03	7.3E-03	7.3E-03
Sodium sulfate, anhydrite {RER} market for Conseq, S	1.4E-02	1.4E-02	1.4E-02	1.4E-02
Steam, in chemical industry {RER} production Conseq, S	8.7E-01	8.7E-01	8.7E-01	8.7E-01
Sulfur trioxide {GLO} market for Conseq, S	1.5E-02	1.5E-02	1.5E-02	1.5E-02
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-9.7E-03	-9.7E-03	-9.7E-03	-9.7E-03
Tap water {GLO} market group for Conseq, S	8.8E-05	8.8E-05	8.8E-05	8.8E-05
Water, completely softened {RER} water production, completely softened Conseq, S	7.0E-03	2.1E-03	2.7E-03	2.9E-03

Jigger Dyeing Process Contributions to End-Point Impact Categories

Table G. 4. Jigger Dyeing Scenarios Process Contributions to Human Health End-point Impact Category

Processes	Sc.2.a	Sc. 2.1	Sc. 2.2	Sc. 2.3
Total	49.9	47.5	50	53.1
Air Emissions	41.7	40.9	43.1	45.5
Water Emissions	-44.7	-43.7	-58.1	-64.9
Alpha-naphthol {RoW} production Conseq, S	5.1E+00	5.1E+00	5.1E+00	5.1E+00
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	3.7E+00	3.7E+00	3.7E+00	3.7E+00
Citric acid {GLO} market for Conseq, S	0	2.0E-01	0	1.2E-01
Cyanuric chloride {GLO} market for Conseq, S	1.4E+00	1.4E+00	1.4E+00	1.4E+00
Electricity, high voltage {GLO} market group for Conseq, S	4.1E+00	4.1E+00	4.1E+00	4.1E+00
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	5.1E+00	4.9E+00

Table G. 4 (cont'd)

Processes	Sc.2.a	Sc. 2.1	Sc. 2.2	Sc. 2.3
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	8.9E-01	0	9.5E-01
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	3.3E-01	3.3E-01	3.3E-01	3.3E-01
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	1.6E-02	1.2E-02
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	2.7E-02	0	1.2E-02
Jigger_only NF_sludge	0	0	4.9E-02	0
Jigger_only UF_sludge	0	5.5E-03	0	0
Jigger_UF+NF_NF_sludge	0	0	0	4.4E-02
Jigger_UF+NF_UF_sludge	0	0	0	5.5E-03
Meta-phenylene diamine {GLO} market for Conseq, S	1.6E+00	1.6E+00	1.6E+00	1.6E+00
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	2.5E+00	2.5E+00	2.5E+00	2.5E+00
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	1.1E-01	9.7E-02
Reactive Orange 12/Golden Yellow HR	1.8E-01	1.8E-01	1.8E-01	1.8E-01
Soap {GLO} market for Conseq, S	2.1E+00	2.1E+00	2.1E+00	2.1E+00
Soda ash, dense {GLO} market for Conseq, S	2.9E-01	2.9E-01	2.9E-01	2.9E-01
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.5E+00	2.5E+00	2.5E+00	2.5E+00
Sodium chloride, powder {GLO} market for Conseq, S	5.9E+00	4.3E-01	1.9E+00	2.5E+00
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	1.4E+00	1.4E+00	1.4E+00	1.4E+00
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	1.5E-01	1.4E-01
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	9.8E-01	0	3.8E-01
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	2.4E+00	0	1.2E+00
Sodium nitrite {GLO} market for Conseq, S	9.0E-01	9.0E-01	9.0E-01	9.0E-01
Sodium sulfate, anhydrite {RER} market for Conseq, S	4.7E-01	4.7E-01	4.7E-01	4.7E-01
Steam, in chemical industry {RER} production Conseq, S	8.8E+00	8.8E+00	8.8E+00	8.8E+00
Sulfur trioxide {GLO} market for Conseq, S	3.7E+00	3.7E+00	3.7E+00	3.7E+00
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	9.6E-01	9.6E-01	9.6E-01	9.6E-01
Tap water {GLO} market group for Conseq, S	1.4E-02	1.4E-02	1.4E-02	1.4E-02
Water, completely softened {RER} water production, completely softened Conseq, S	2.0E+00	5.4E-01	7.1E-01	8.2E-01

Table G. 5. Jigger Dyeing Scenarios Process Contributions to Ecosystems End-point Impact Category

Processes	Sc.2.a	Sc. 2.1	Sc. 2.2	Sc. 2.3
Total	1.82	1.66	1.73	1.81
Air Emissions	1.21	1.18	1.23	1.28
Water Emissions	-5.48	-5.29	-6.85	-7.64
Alpha-naphthol {RoW} production Conseq, S	1.5E-01	1.5E-01	1.5E-01	1.5E-01
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	1.7E-01	1.7E-01	1.7E-01	1.7E-01
Citric acid {GLO} market for Conseq, S	0	5.9E-03	0	3.4E-03
Cyanuric chloride {GLO} market for Conseq, S	4.6E-02	4.6E-02	4.6E-02	4.6E-02
Electricity, high voltage {GLO} market group for Conseq, S	9.3E-02	9.3E-02	9.3E-02	9.3E-02
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	1.2E-01	1.1E-01
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	2.0E-02	0	2.1E-02
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	5.4E-03	5.4E-03	5.4E-03	5.4E-03
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	2.5E-04	1.9E-04
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	4.4E-04	0	1.9E-04
Jigger_only NF_sludge	0	0	7.7E-03	0
Jigger_only UF_sludge	0	2.1E-03	0	0
Jigger_UF+NF_NF_sludge	0	0	0	5.9E-03
Jigger_UF+NF_UF_sludge	0	0	0	2.1E-03
Meta-phenylene diamine {GLO} market for Conseq, S	4.6E-02	4.6E-02	4.6E-02	4.6E-02
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.5E-01	1.5E-01	1.5E-01	1.5E-01
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	2.4E-03	2.2E-03
Reactive Orange 12/Golden Yellow HR	2.7E-02	2.7E-02	2.7E-02	2.7E-02
Soap {GLO} market for Conseq, S	1.5E-01	1.5E-01	1.5E-01	1.5E-01

Table G. 5 (cont'd)

Processes	Sc.2.a	Sc. 2.1	Sc. 2.2	Sc. 2.3
Soda ash, dense {GLO} market for Conseq, S	1.8E-02	1.8E-02	1.8E-02	1.8E-02
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	7.2E-02	7.2E-02	7.2E-02	7.2E-02
Sodium chloride, powder {GLO} market for Conseq, S	1.6E-01	1.2E-02	5.2E-02	6.8E-02
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	4.1E-02	4.1E-02	4.1E-02	4.1E-02
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	4.5E-03	4.2E-03
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	2.9E-02	0	1.1E-02
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	5.8E-02	0	2.7E-02
Sodium nitrite {GLO} market for Conseq, S	2.5E-02	2.5E-02	2.5E-02	2.5E-02
Sodium sulfate, anhydrite {RER} market for Conseq, S	1.4E-02	1.4E-02	1.4E-02	1.4E-02
Steam, in chemical industry {RER} production Conseq, S	3.5E-01	3.5E-01	3.5E-01	3.5E-01
Sulfur trioxide {GLO} market for Conseq, S	8.5E-02	8.5E-02	8.5E-02	8.5E-02
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	1.6E-02	1.6E-02	1.6E-02	1.6E-02
Tap water {GLO} market group for Conseq, S	6.5E-04	6.5E-04	6.5E-04	6.5E-04
Water, completely softened {RER} water production, completely softened Conseq, S	1.6E-01	4.5E-02	5.9E-02	6.9E-02

Table G. 6. Jigger Dyeing Scenarios Process Contributions to Resources End-point Impact Category

Processes	Sc.2.a	Sc. 2.1	Sc. 2.2	Sc. 2.3
Total	0.86	0.83	0.86	0.88
Air Emissions	0	0	0	0
Water Emissions	0	0	0	0
Alpha-naphthol {RoW} production Conseq, S	1.2E-01	1.2E-01	1.2E-01	1.2E-01
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	1.7E-01	1.7E-01	1.7E-01	1.7E-01
Citric acid {GLO} market for Conseq, S	0	9.4E-04	0	5.4E-04

Table G. 6 (cont'd)

Processes	Sc.2.a	Sc. 2.1	Sc. 2.2	Sc. 2.3
Cyanuric chloride {GLO} market for Conseq, S	4.0E-02	4.0E-02	4.0E-02	4.0E-02
Electricity, high voltage {GLO} market group for Conseq, S	3.2E-02	3.2E-02	3.2E-02	3.2E-02
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	4.0E-02	3.8E-02
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	6.9E-03	0	7.3E-03
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	5.5E-03	5.5E-03	5.5E-03	5.5E-03
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	2.6E-04	1.9E-04
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	4.5E-04	0	1.9E-04
Jigger_only NF_sludge	0	0	0	0
Jigger_only UF_sludge	0	0	0	0
Jigger_UF+NF_NF_sludge	0	0	0	0
Jigger_UF+NF_UF_sludge	0	0	0	0
Meta-phenylene diamine {GLO} market for Conseq, S	3.2E-02	3.2E-02	3.2E-02	3.2E-02
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	7.0E-02	7.0E-02	7.0E-02	7.0E-02
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	3.0E-04	2.8E-04
Reactive Orange 12/Golden Yellow HR	0	0	0	0
Soap {GLO} market for Conseq, S	7.2E-03	7.2E-03	7.2E-03	7.2E-03
Soda ash, dense {GLO} market for Conseq, S	8.2E-03	8.2E-03	8.2E-03	8.2E-03
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.9E-04	2.9E-04	2.9E-04	2.9E-04
Sodium chloride, powder {GLO} market for Conseq, S	4.5E-02	3.3E-03	1.4E-02	1.9E-02
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	-3.3E-04	-3.3E-04	-3.3E-04	-3.3E-04
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	-3.5E-05	-3.3E-05
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	-2.3E-04	0	-8.9E-05
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	1.6E-02	0	7.5E-03
Sodium nitrite {GLO} market for Conseq, S	7.3E-03	7.3E-03	7.3E-03	7.3E-03
Sodium sulfate, anhydrite {RER} market for Conseq, S	1.4E-02	1.4E-02	1.4E-02	1.4E-02

Table G. 6 (cont'd)

Processes	Sc.2.a	Sc. 2.1	Sc. 2.2	Sc. 2.3
Steam, in chemical industry {RER} production Conseq, S	2.9E-01	2.9E-01	2.9E-01	2.9E-01
Sulfur trioxide {GLO} market for Conseq, S	1.5E-02	1.5E-02	1.5E-02	1.5E-02
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-9.7E-03	-9.7E-03	-9.7E-03	-9.7E-03
Tap water {GLO} market group for Conseq, S	8.8E-05	8.8E-05	8.8E-05	8.8E-05
Water, completely softened {RER} water production, completely softened Conseq, S	5.2E-03	1.4E-03	1.9E-03	2.2E-03

Pad-Steam Dyeing Process Contributions to End-Point Impact Categories

Table G. 7. Pad Dyeing Scenarios Process Contributions to Human Health End-point Impact Category

Processes	Sc.3.a	Sc. 3.1	Sc. 3.2	Sc. 3.3
Total	76.1	73.1	75.9	78.4
Air Emissions	67.4	65.8	68.1	70.2
Water Emissions	-41.9	-38.9	-51.5	-57.8
Alpha-naphthol {RoW} production Conseq, S	5.1E+00	5.1E+00	5.1E+00	5.1E+00
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	3.7E+00	3.7E+00	3.7E+00	3.7E+00
Citric acid {GLO} market for Conseq, S	0	1.5E-01	0	9.5E-02
Cyanuric chloride {GLO} market for Conseq, S	1.4E+00	1.4E+00	1.4E+00	1.4E+00
Electricity, high voltage {GLO} market group for Conseq, S	2.9E+00	2.9E+00	2.9E+00	2.9E+00
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	4.1E+00	4.1E+00
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	6.8E-01	0	7.2E-01
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	3.3E-01	3.3E-01	3.3E-01	3.3E-01
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	1.2E-02	7.9E-03
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	2.0E-02	0	1.2E-02
Meta-phenylene diamine {GLO} market for Conseq, S	1.6E+00	1.6E+00	1.6E+00	1.6E+00
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	2.5E+00	2.5E+00	2.5E+00	2.5E+00
Pad_only NF_sludge	0	0	4.9E-02	0
Pad_only UF_sludge	0	5.5E-03	0	0
Pad_UF+NF_NF_sludge	0	0	0	4.4E-02

Table G. 7 (cont'd)

Processes	Sc.3.a	Sc. 3.1	Sc. 3.2	Sc. 3.3
Pad_UF+NF_UF_sludge	0	0	0	5.5E-03
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	7.9E-02	7.3E-02
Reactive Orange 12/Golden Yellow HR	1.8E-01	1.8E-01	1.8E-01	1.8E-01
Soap {GLO} market for Conseq, S	2.1E+00	2.1E+00	2.1E+00	2.1E+00
Soda ash, dense {GLO} market for Conseq, S	2.9E-01	2.9E-01	2.9E-01	2.9E-01
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.5E+00	2.5E+00	2.5E+00	2.5E+00
Sodium chloride, powder {GLO} market for Conseq, S	5.9E+00	4.7E-01	2.1E+00	2.5E+00
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	1.4E+00	1.4E+00	1.4E+00	1.4E+00
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	1.1E-01	1.1E-01
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	7.4E-01	0	3.2E-01
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	1.8E+00	0	9.6E-01
Sodium nitrite {GLO} market for Conseq, S	9.0E-01	9.0E-01	9.0E-01	9.0E-01
Sodium sulfate, anhydrite {RER} market for Conseq, S	4.7E-01	4.7E-01	4.7E-01	4.7E-01
Steam, in chemical industry {RER} production Conseq, S	2.9E+01	2.9E+01	2.9E+01	2.9E+01
Sulfur trioxide {GLO} market for Conseq, S	3.7E+00	3.7E+00	3.7E+00	3.7E+00
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	9.6E-01	9.6E-01	9.6E-01	9.6E-01
Tap water {GLO} market group for Conseq, S	1.4E-02	1.4E-02	1.4E-02	1.4E-02
Urea {RER} market for urea Conseq, S	1.1E+00	1.1E+00	1.1E+00	1.1E+00
Water, completely softened {RER} water production, completely softened Conseq, S	1.3E+00	4.0E-01	5.8E-01	6.4E-01

Table G. 8. Pad Dyeing Scenarios Process Contributions to Ecosystems End-point Impact Category

Processes	Sc.3.a	Sc. 3.1	Sc. 3.2	Sc. 3.3
Total	2.69	2.55	2.62	2.69
Air Emissions	2.06	2.01	2.06	2.11
Water Emissions	-5.4	-4.98	-6.37	-7.08
Alpha-naphthol {RoW} production Conseq, S	1.5E-01	1.5E-01	1.5E-01	1.5E-01
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	1.7E-01	1.7E-01	1.7E-01	1.7E-01
Citric acid {GLO} market for Conseq, S	0	4.4E-03	0	2.8E-03
Cyanuric chloride {GLO} market for Conseq, S	4.6E-02	4.6E-02	4.6E-02	4.6E-02

Table G. 8 (cont'd)

Processes	Sc.3.a	Sc. 3.1	Sc. 3.2	Sc. 3.3
Electricity, high voltage {GLO} market group for Conseq, S	6.6E-02	6.6E-02	6.6E-02	6.6E-02
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	9.2E-02	9.3E-02
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	1.5E-02	0	1.6E-02
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	5.4E-03	5.4E-03	5.4E-03	5.4E-03
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	1.9E-04	1.3E-04
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	3.2E-04	0	1.9E-04
Meta-phenylene diamine {GLO} market for Conseq, S	4.6E-02	4.6E-02	4.6E-02	4.6E-02
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	1.5E-01	1.5E-01	1.5E-01	1.5E-01
Pad_only NF_sludge	0	0	7.7E-03	0
Pad_only UF_sludge	0	2.1E-03	0	0
Pad_UF+NF_NF_sludge	0	0	0	5.9E-03
Pad_UF+NF_UF_sludge	0	0	0	2.1E-03
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	1.8E-03	1.7E-03
Reactive Orange 12/Golden Yellow HR	2.7E-02	2.7E-02	2.7E-02	2.7E-02
Soap {GLO} market for Conseq, S	1.5E-01	1.5E-01	1.5E-01	1.5E-01
Soda ash, dense {GLO} market for Conseq, S	1.8E-02	1.8E-02	1.8E-02	1.8E-02
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	7.2E-02	7.2E-02	7.2E-02	7.2E-02
Sodium chloride, powder {GLO} market for Conseq, S	1.6E-01	1.3E-02	5.9E-02	6.9E-02
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	4.1E-02	4.1E-02	4.1E-02	4.1E-02
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	3.3E-03	3.1E-03
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	2.2E-02	0	9.5E-03
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	4.3E-02	0	2.3E-02
Sodium nitrite {GLO} market for Conseq, S	2.5E-02	2.5E-02	2.5E-02	2.5E-02
Sodium sulfate, anhydrite {RER} market for Conseq, S	1.4E-02	1.4E-02	1.4E-02	1.4E-02
Steam, in chemical industry {RER} production Conseq, S	1.2E+00	1.2E+00	1.2E+00	1.2E+00
Sulfur trioxide {GLO} market for Conseq, S	8.5E-02	8.5E-02	8.5E-02	8.5E-02
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	1.6E-02	1.6E-02	1.6E-02	1.6E-02

Table G. 8 (cont'd)

Processes	Sc.3.a	Sc. 3.1	Sc. 3.2	Sc. 3.3
Tap water {GLO} market group for Conseq, S	6.5E-04	6.5E-04	6.5E-04	6.5E-04
Urea {RER} market for urea Conseq, S	4.9E-02	4.9E-02	4.9E-02	4.9E-02
Water, completely softened {RER} water production, completely softened Conseq, S	1.1E-01	3.4E-02	4.9E-02	5.4E-02

Table G. 9. Pad Dyeing Scenarios Process Contributions to Resources End-point Impact Category

Processes	Sc.3.a	Sc. 3.1	Sc. 3.2	Sc. 3.3
Total	1.58	1.55	1.58	1.60
Air Emissions	0	0	0	0
Water Emissions	0	0	0	0
Alpha-naphthol {RoW} production Conseq, S	1.2E-01	1.2E-01	1.2E-01	1.2E-01
Ammonia, anhydrous, liquid {RER} market for ammonia, anhydrous, liquid Conseq, S	1.7E-01	1.7E-01	1.7E-01	1.7E-01
Citric acid {GLO} market for Conseq, S	0	6.9E-04	0	4.4E-04
Cyanuric chloride {GLO} market for Conseq, S	4.0E-02	4.0E-02	4.0E-02	4.0E-02
Electricity, high voltage {GLO} market group for Conseq, S	2.3E-02	2.3E-02	2.3E-02	2.3E-02
Electricity, high voltage {GLO} market group for Conseq, S_NF	0	0	3.1E-02	3.2E-02
Electricity, high voltage {GLO} market group for Conseq, S_UF	0	5.3E-03	0	5.6E-03
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S	5.5E-03	5.5E-03	5.5E-03	5.5E-03
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_NF	0	0	1.9E-04	1.3E-04
Hydrochloric acid, without water, in 30% solution state {RoW} market for Conseq, S_UF	0	3.2E-04	0	1.9E-04
Meta-phenylene diamine {GLO} market for Conseq, S	3.2E-02	3.2E-02	3.2E-02	3.2E-02
Non-ionic surfactant {GLO} market for non-ionic surfactant Conseq, S	7.0E-02	7.0E-02	7.0E-02	7.0E-02
Pad_only NF_sludge	0	0	0	0
Pad_only UF_sludge	0	0	0	0
Pad_UF+NF_NF_sludge	0	0	0	0
Pad_UF+NF_UF_sludge	0	0	0	0
Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Conseq, S	0	0	2.3E-04	2.1E-04
Reactive Orange 12/Golden Yellow HR	0	0	0	0
Soap {GLO} market for Conseq, S	7.2E-03	7.2E-03	7.2E-03	7.2E-03

Table G. 9 (cont'd)

Processes	Sc.3.a	Sc. 3.1	Sc. 3.2	Sc. 3.3
Soda ash, dense {GLO} market for Conseq, S	8.2E-03	8.2E-03	8.2E-03	8.2E-03
Sodium bicarbonate {GLO} market for sodium bicarbonate Conseq, S	2.9E-04	2.9E-04	2.9E-04	2.9E-04
Sodium chloride, powder {GLO} market for Conseq, S	4.5E-02	3.5E-03	1.6E-02	1.9E-02
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S	-3.3E-04	-3.3E-04	-3.3E-04	-3.3E-04
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_NF	0	0	-2.6E-05	-2.5E-05
Sodium hydroxide, without water, in 50% solution state {GLO} market for Conseq, S_UF	0	-1.7E-04	0	-7.5E-05
Sodium hypochlorite, without water, in 15% solution state {GLO} market for Conseq, S	0	1.2E-02	0	6.2E-03
Sodium nitrite {GLO} market for Conseq, S	7.3E-03	7.3E-03	7.3E-03	7.3E-03
Sodium sulfate, anhydrite {RER} market for Conseq, S	1.4E-02	1.4E-02	1.4E-02	1.4E-02
Steam, in chemical industry {RER} production Conseq, S	9.7E-01	9.7E-01	9.7E-01	9.7E-01
Sulfur trioxide {GLO} market for Conseq, S	1.5E-02	1.5E-02	1.5E-02	1.5E-02
Sulfuric acid {RoW} market for sulfuric acid Conseq, S	-9.7E-03	-9.7E-03	-9.7E-03	-9.7E-03
Tap water {GLO} market group for Conseq, S	8.8E-05	8.8E-05	8.8E-05	8.8E-05
Urea {RER} market for urea Conseq, S	5.5E-02	5.5E-02	5.5E-02	5.5E-02
Water, completely softened {RER} water production, completely softened Conseq, S	3.5E-03	1.1E-03	1.6E-03	1.7E-03

H. Tree Diagrams of Scenarios

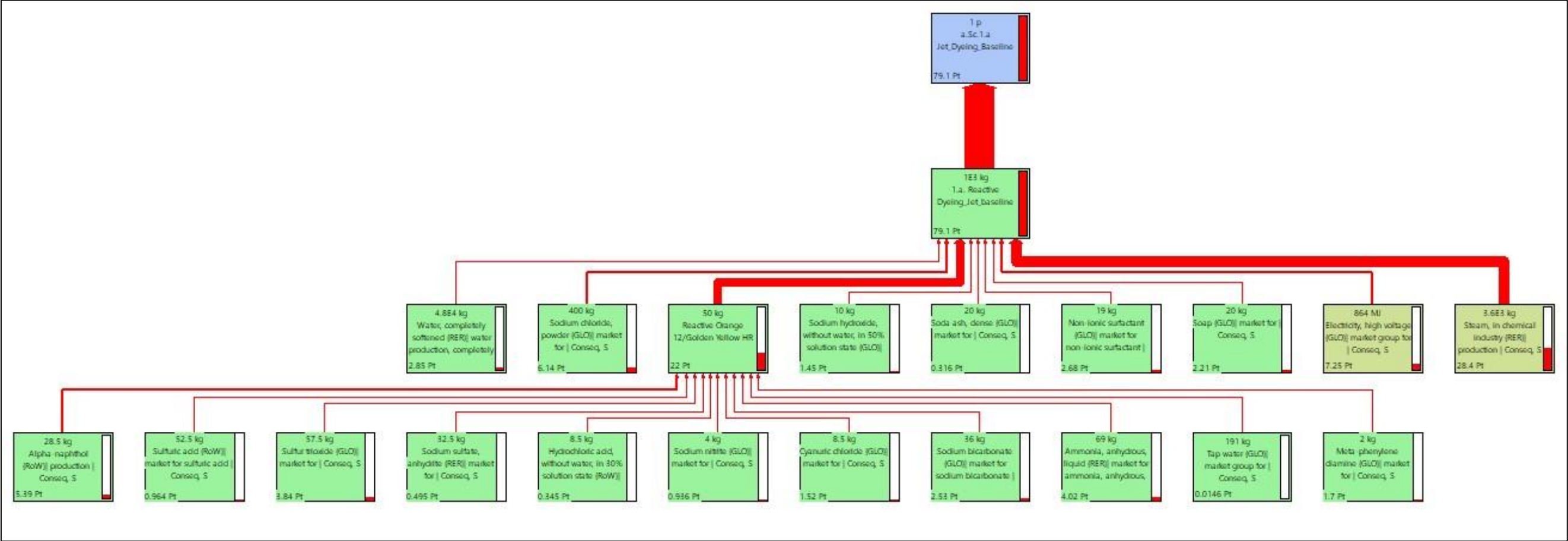


Figure H. 1. Tree Diagram of Scenario 1.a

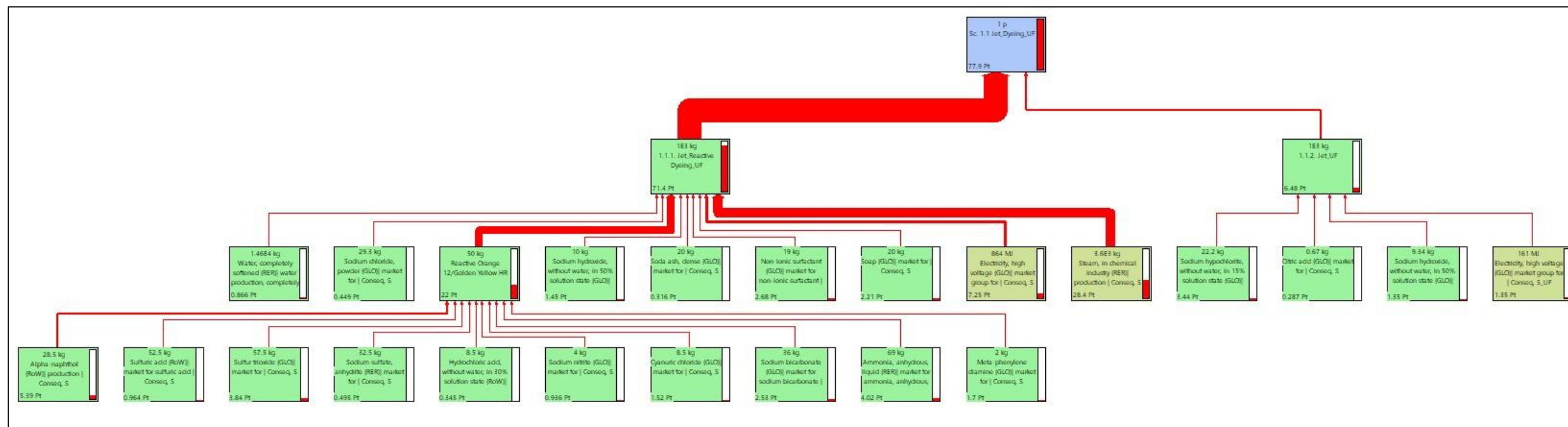


Figure H. 2. Tree Diagram of Scenario 1.1

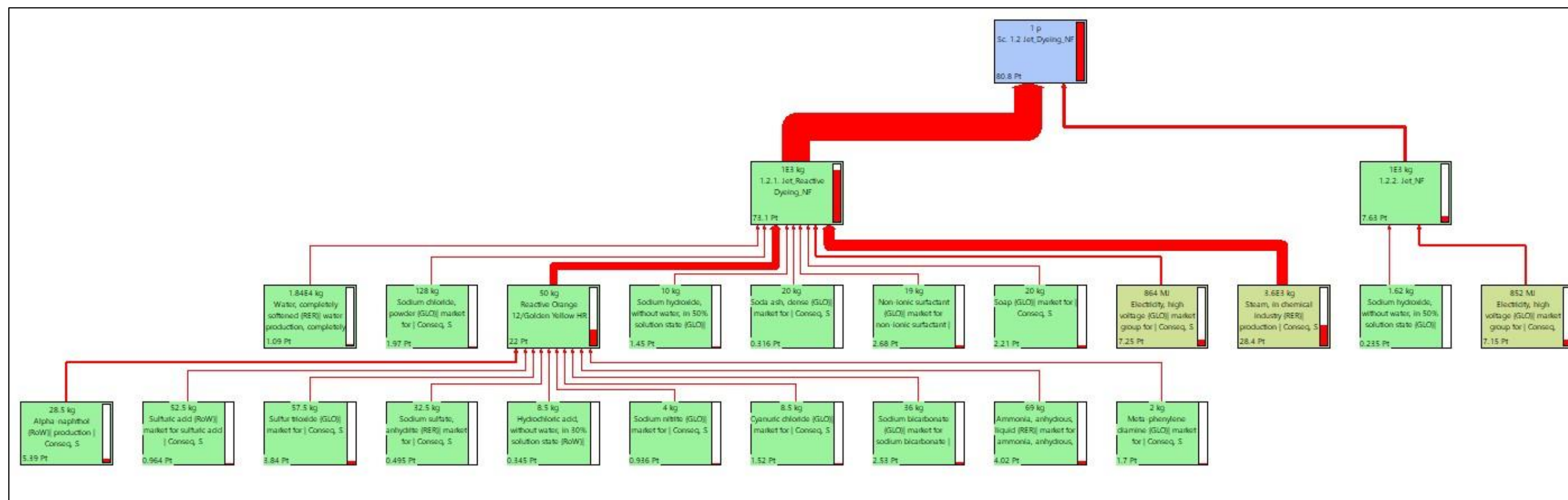


Figure H. 3. Tree Diagram of Scenario 1.2

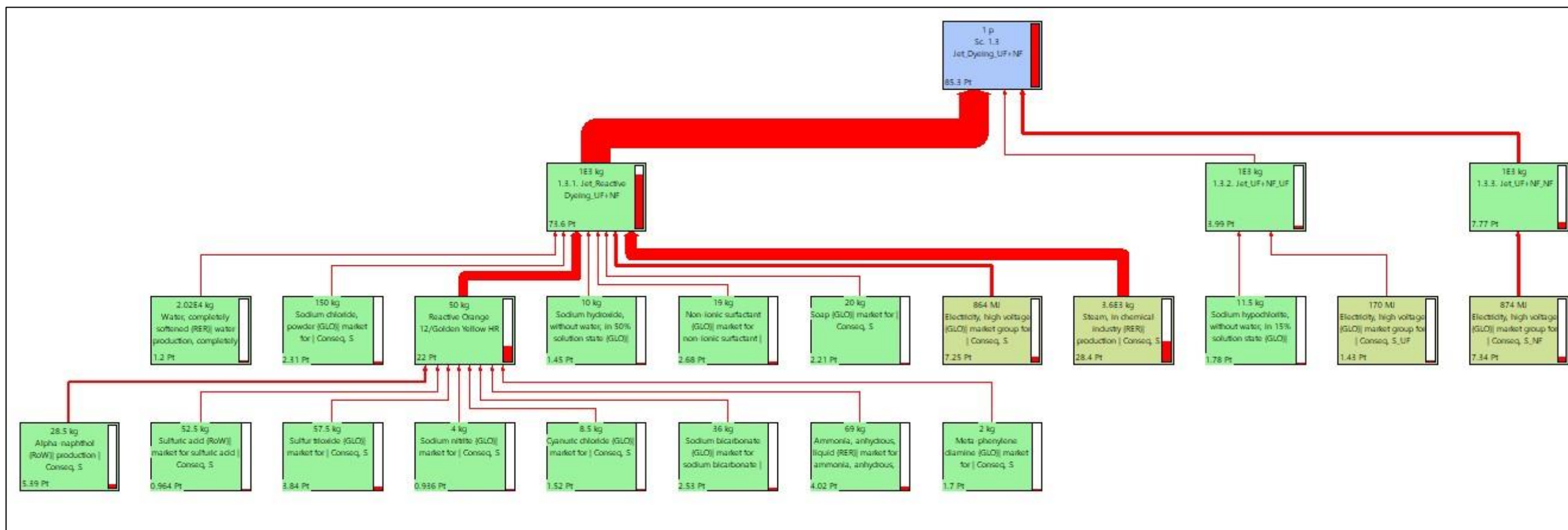


Figure H. 4. Tree Diagram of Scenario 1.3

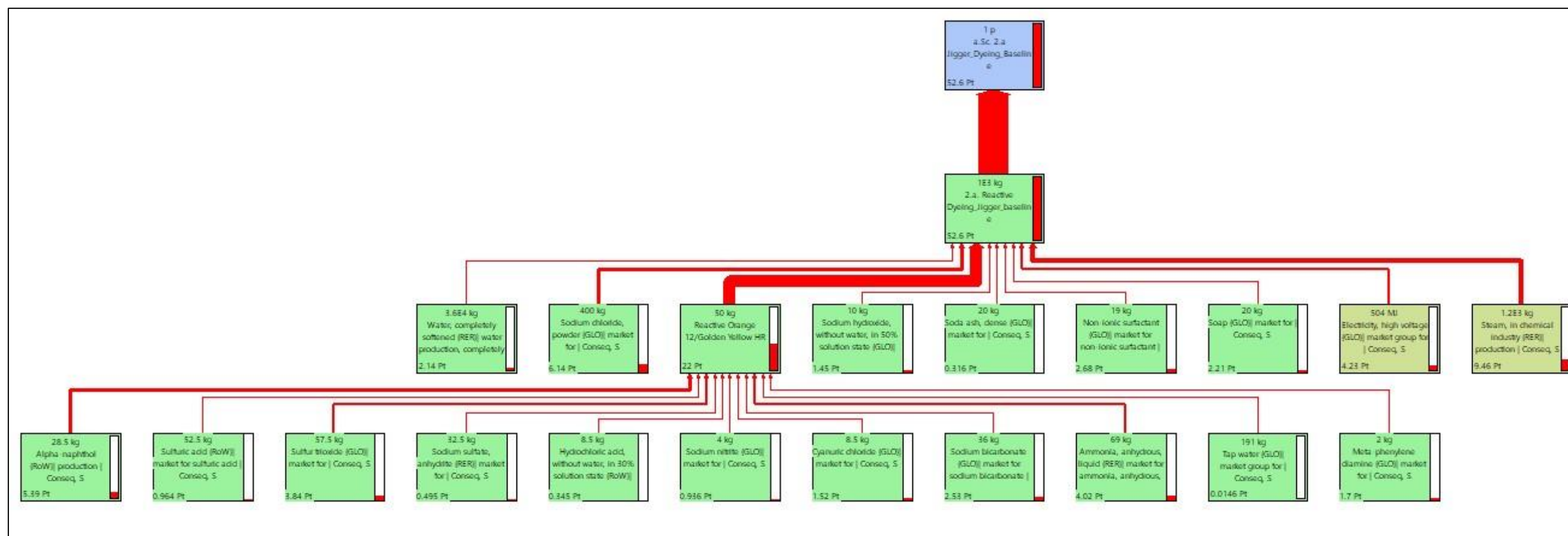


Figure H. 5. Tree Diagram of Scenario 2.a

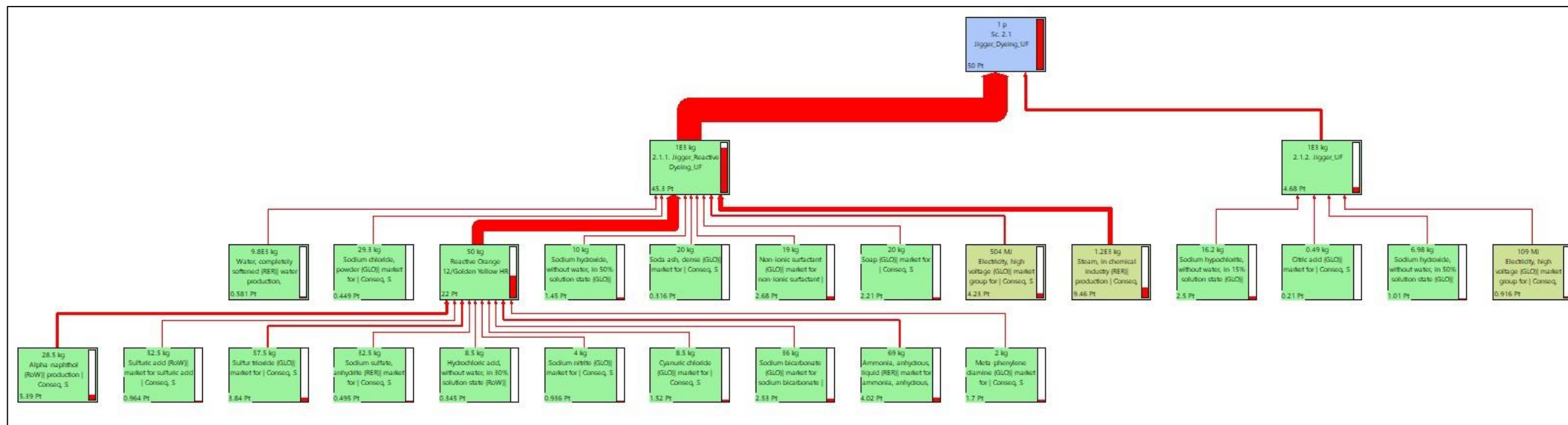


Figure H. 6. Tree Diagram of Scenario 2.1

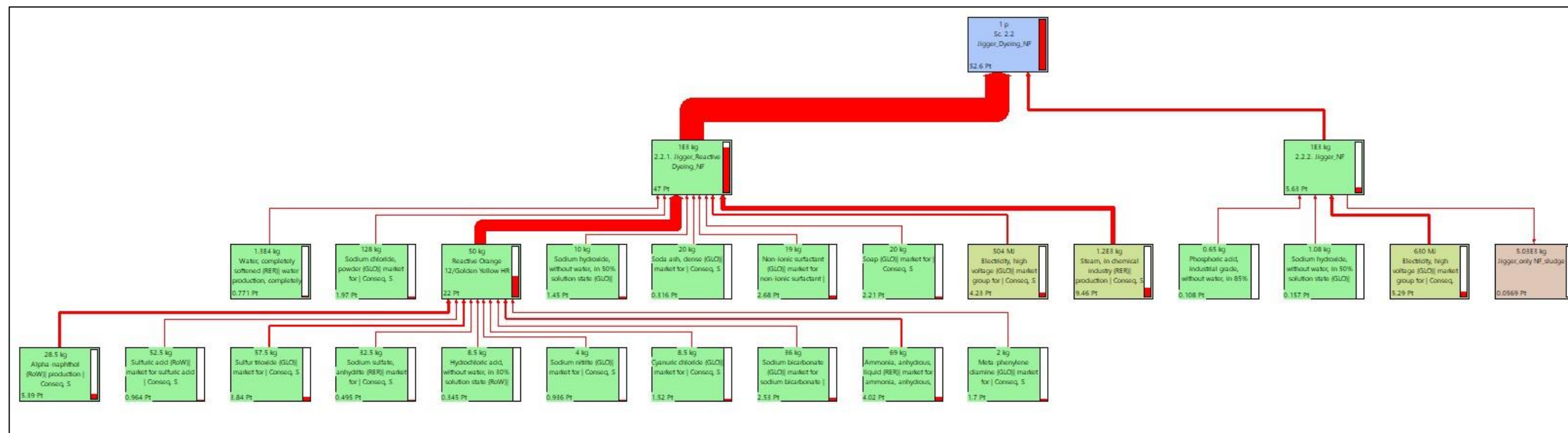


Figure H. 7. Tree Diagram of Scenario 2.2

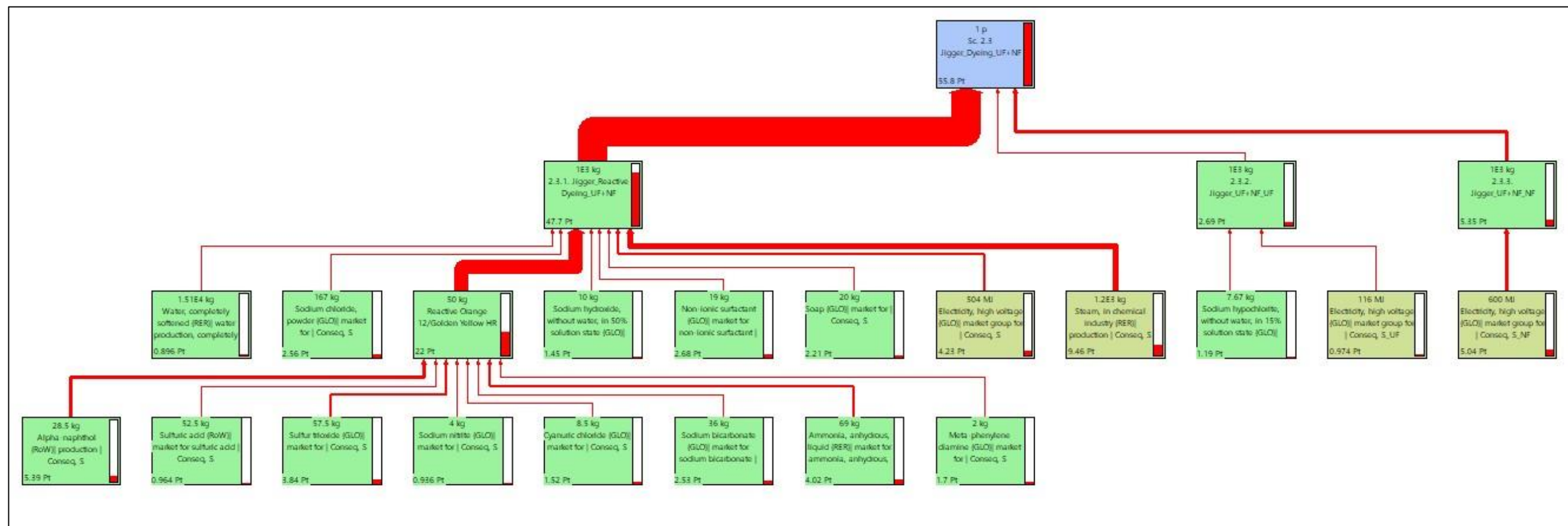


Figure H. 8. Tree Diagram of Scenario 2.3

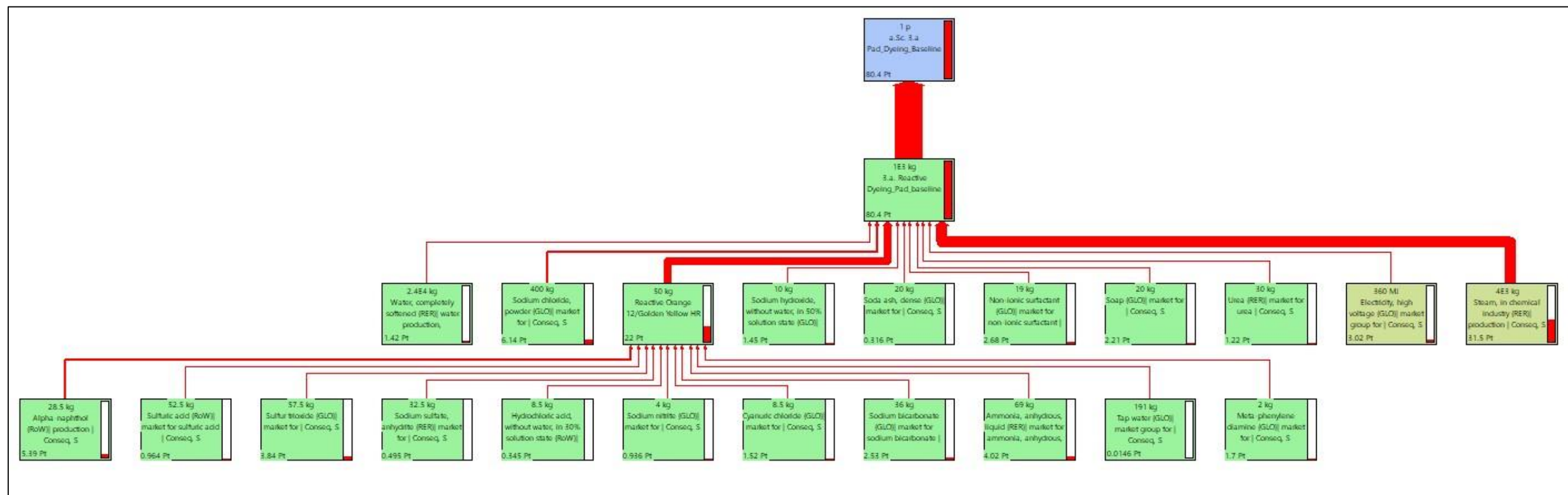


Figure H. 9. Tree Diagram of Scenario 3.a

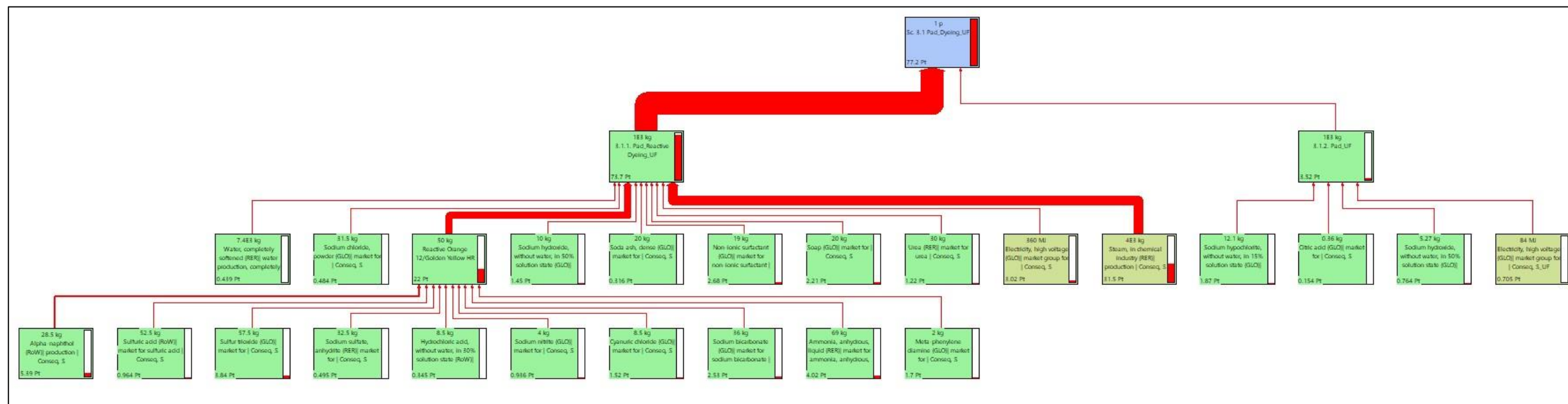


Figure H. 10. Tree Diagram of Scenario 3.1

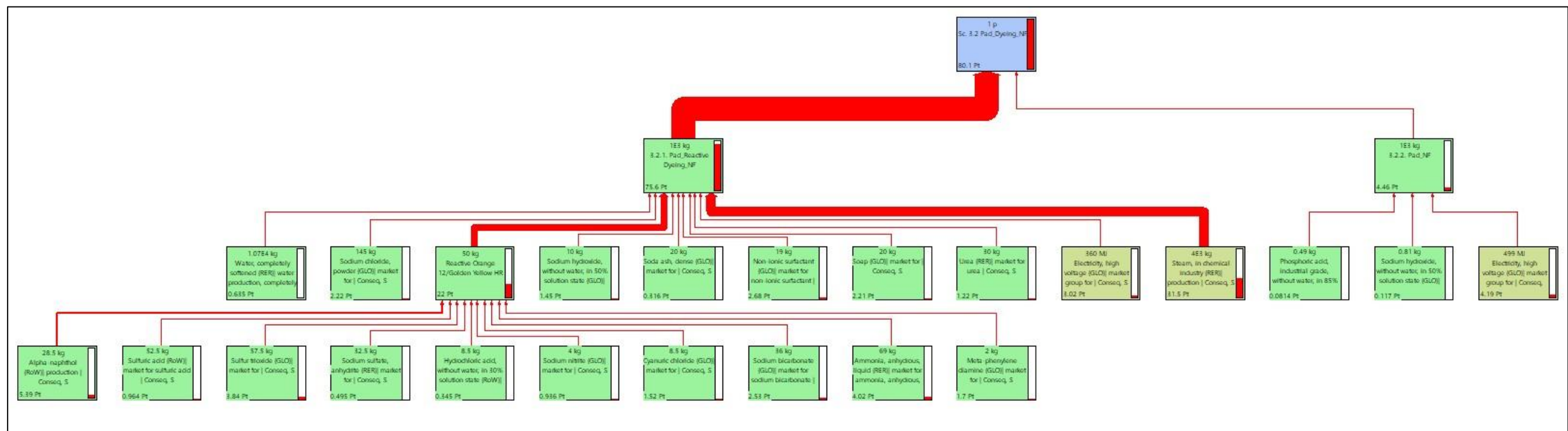


Figure H. 11. Tree Diagram of Scenario 3.2

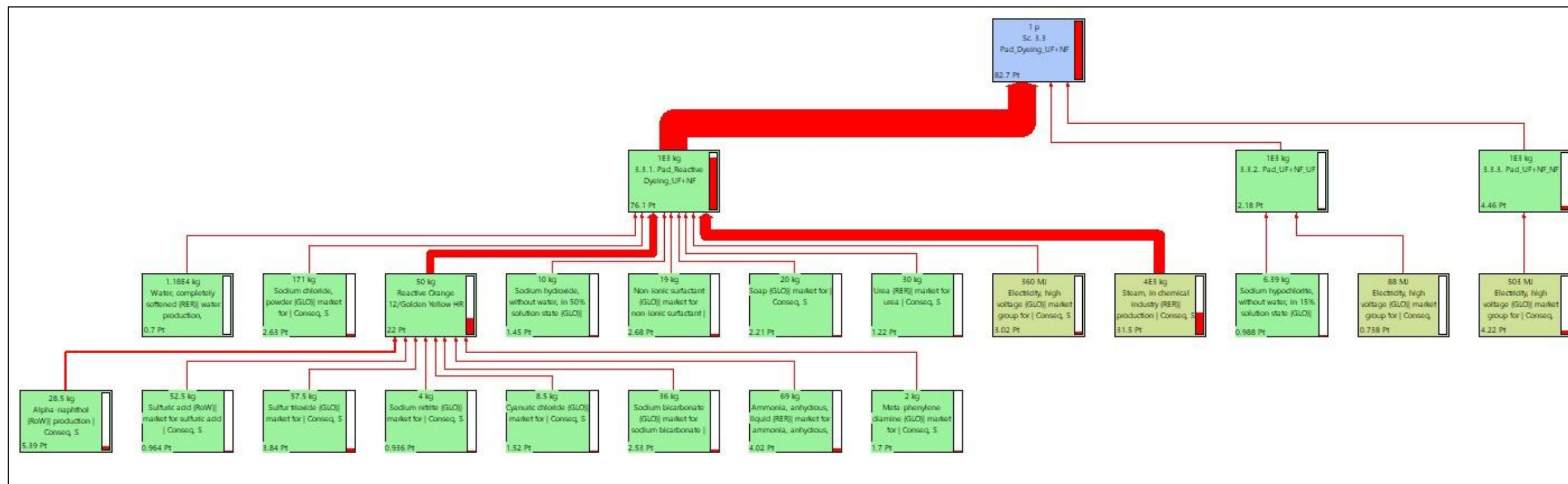


Figure H. 12. Tree Diagram of Scenario 3.3